THE STORY OF ANIMAL LIFE

VOLUME I
THE FRAMEWORK OF ANIMAL LIFE
INVERTEBRATES

VOLUME II
VERTEBRATES

LIST OF CONTRIBUTORS

GREAT BRITAIN

* G. D. HALE CARPENTER, D. M. (Oxon), Professor Emeritus of Zoology (Entomology), University of Oxford: author of works on insect coloration and distribution
* BEN DAWES, D. Sc., Reader in Zoology, University of London
J. P. HARDING, Ph. D., Zoology Department, British Museum (Natural History)
D. DILWYN JOHN, D. Sc., Director, National Museum of Wales; late of "Discovery" Investigations in the Antarctic
S. M. MANTON, Sc. D., F. R. S., Reader in Zoology, University of London
GILBERT NIXON, B. A., Commonwealth Institute of Entomology
* F. D. OMMANNEY, Ph. D., Marine Biologist with the Mauritius and Seychelles Fishery Service: late of "Discovery" Investigations in the Antarctic
* THEODORE H. SAVORY, M. A., Malvern College
* W. E. SWINTON, Ph. D., Department of Geology, British Museum (Natural History)

U. S. A.

* GEORGE C. CRILE, Surgeon and Founder of a Research Museum
* C. H. CURRAN, D. Sc., American Museum of Natural History, New York
* MAX W. DE LAUBENFELS, Professor of Zoology, University of Hawaii
THOMAS ELLIOTT SNYDER, M. F., Ph. D., Senior Entomologist, Forest Insects Investigations, Bureau of Entomology and Plant Quarantine, Washington 25, D.C.

HOLLAND

G. BARENDRECHT, Zoological Laboratory, Department of Entomology, University of Amsterdam

DENMARK

TH. MORTENSEN, Ph. D., Zoological Museum, Copenhagen

* These contributors are authors of books on natural history

The Story of
ANIMAL LIFE

by

MAURICE BURTON, D. SC.

DEPUTY KEEPER, DEPARTMENT OF ZOOLOGY
BRITISH MUSEUM (NATURAL HISTORY) LONDON

With special articles contributed by
Zoologists of various countries

IN TWO VOLUMES
WITH OVER 1000 ILLUSTRATIONS
IN BLACK AND WHITE
AND COLOUR

VOLUME I

THE FRAMEWORK OF ANIMAL LIFE
INVERTEBRATES

LONDON
ELSEVIER PUBLISHING CO., LTD.

ELSEVIER PUBLISHING CO., LTD.
LONDON: 42a SOUTH AUDLEY STREET W.1
ASSOCIATED COMPANIES IN AMSTERDAM, NEW YORK AND BRUSSELS
First published 1949
ALL RIGHTS RESERVED

PRINTED IN THE NETHERLANDS BY N.V. DRUKKERIJ G. J. THIEME, NIJMEGEN

PREFACE

So far as we can tell, living matter has existed on the earth for two thousand million years, and during this time plants and animals have adjusted and adapted themselves by trial and error to a reasonable equilibrium. Man has a history of less than one million years and, especially during the last few thousand years, has sought to conquer Nature. He has thereby produced for himself inhibitions and frustrations and false standards. If future generations of mankind are not to find themselves overburdened with a monster of man's own creation, they must study their natural heritage, seeking a closer knowledge and alliance with Nature.

While physics, with its researches into atomic power, tends to hold the attention of the world, biological science, about which much less is heard, appears to be on the threshold of far-reaching discoveries which will affect the lives of human beings more deeply, if more subtly. And whereas the harnessing of atomic energy can only mean power in the hands of the relatively few, the benefits of biological science can be reaped by the many by direct application to their everyday lives. Indeed, this is the only way. Man also is, and must be recognised as, a biological unit whose welfare is largely in his own hands.

There is no doubt that the human race is faced in the measurable future with universal shortages, if not starvation, unless a wiser and more sympathetic handling of the living world, and particularly of animal life, is effected. Only the informed, intelligent and sympathetic participation of a majority of the world's inhabitants can translate the urgent needs into adequate action in a sufficiently short space of time. This implies an education on a very wide scale, and throws a heavy responsibility on those who form the ideas of the public at large — on the school, the university, and the museum, and on all who write, whether in daily paper, weekly review or published book.

Too often the acquisition of knowledge for knowledge's sake is derided. Yet again and again the lesson has been pointed that the seemingly unimportant is, in fact, the all important. Who of the early microscopists who studied out of sheer interest the minute foraminifera could have foreseen their great significance in the search for petroleum? To-day, the systematic study of the foraminifera is regarded as being of such importance that it is heavily subsidised by the oil companies themselves. Or, again, what could be more seemingly unimportant, economically, than the tunicates, yet, if we knew more of the life-histories of these strange animals, a solution of the fouling of ships' bottoms, so costly annually in time, materials and money, might be nearer attainment.

This book is a survey of the whole Animal Kingdom. The aim of its compilers is to examine the classification, structure and behaviour of animals against an evolutionary background in such a way that the reader may develop an appreciation of the long history of the animal world, its relationship with the rest of the living world and the underlying motives of animal behaviour. With this picture in mind he will be able not only to appreciate the world around but to see in perspective the function of his own body and personality. We have also had in mind the requirements of the teacher of biology, on whose treatment of the subject hinges so largely whether future generations will make the fullest use of our biological knowledge, but it is hoped that the book will be well within the range of the interested non-biologist.

With regard to illustrations, it has been a particular aim to secure those of living animals in practically all cases, to the exclusion of stuffed figures, paintings and the like which feature in so many books. By an extensive search of sources in Britain, Europe and America it has been possible to find photographs of practically all the more notable species which possess pictorial value and show the essential characteristics; while many of them further illustrate principles of behaviour which are significant throughout the animal kingdom.

Taxonomy—a system of classification—is to the zoologist as the fixed points to the navigator; and it is hoped that the reader will derive a sufficient understanding of it to serve as a convenient base for the exploration of the vast volume of current writing on natural history. If the book offers no more than a means of correlating what is contained in the literature of the subject, it will have fulfilled its purpose.

CONTENTS

Preface v
Acknowledgements xi
Introduction 1
The Meaning of Zoology: *By Dr. W. E. Swinton* 3
The Study of Systematics or Taxonomy 13
Table: Classification of the Animal Kingdom 20

CHAPTER I
THE ORIGIN OF LIFE

The Obscure Past: when and how did Life begin?: *By Dr. W. E. Swinton* . 21
The Viruses: a Bridge between the living and the non-living: *By Dr. W. E. Swinton* 24
The Fundamental Needs of Living Matter 28
The Simplest Animal 28
Reproduction: the Continuity of Life . 30
The Living Cell 30
The Simplest Form of Animal Behaviour 32
The Primary Mechanism of Organic Evolution 34
What is an Animal? 37
Table to show the number of eggs laid each year by a few typical marine animals 39

CHAPTER II
THE MECHANISM OF LIFE

Living and Growing 41
The Importance of Reproduction . . 43
Unicellular and Multicellular Animals . 44
The Multiplication of Cells . . . 46
The Origin and Evolution of Sex . 47
Secondary Sexual Characters . . . 49
Reproduction without Sex . . . 50
Offspring which do not resemble their Parents 51
The Theory of Evolution . . . 52

CHAPTER III
THE HISTORY OF LIFE

The Geological Record: *By Dr. W. E. Swinton* 55
Table of the Geological Record and the Succession of Animal Life . . . 58
Living Fossils: *By Dr. W. E. Swinton* . 64
Animals that have recently become Extinct: *By Dr. W. E. Swinton* . . 67
The Extermination of the Passenger Pigeon 70
Rare Animals 72

CHAPTER IV
THE EXPRESSION OF LIFE

The Meaning of Behaviour . . . 73
The Similarity of Behaviour in all Animals 74
The Analysis of Behaviour . . . 81
Tropism in Animals: *By Theodore H. Savory, M.A.* 85
The Sacred Flame and its Devotees . 91
Egg Populations and Parental Care . 94

CHAPTER V
THE BACKGROUND OF LIFE

The Animal and its Surroundings . 95
The Analysis of Animal Communities 95
The Structure of Habitats . . . 97
The Delicacy and Stability of Natural Balance 102
The Study of Animal Populations . 104

The Far-reaching Effects of Trace Elements 105
The African Front: *By Dr. George Crile* 107
Animals Known from a Single Specimen 116
Food Chains 118

CHAPTER VI
THE CRADLE OF LIFE

Life in the Sea: *By Dr. D. Dilwyn John* 119
Life under the Sea: *By Professor M. W. de Laubenfels* 129

CHAPTER VII
THE FIRST ANIMALS

The Unicellular Animals (Phylum Protozoa) 135
The Phylum Sponges 143
New Bodies for Old: Regeneration in the Animal Kingdom 147

CHAPTER VIII
PHYLUM COELENTERATA

Diploblastic and Triploblastic Animals 149
Nematocysts, Stinging- or Nettle-cells . 149
The Alternation of Generations . . 150
Sea Firs, Jellyfish, Sea-anemones and Corals 152
The Formation of Coral Reefs: *By Dr. J. D. Ommanney* 158

CHAPTER IX
VERMES, OR WORMS

Bristle Worms and Parasitic Worms . 163
Helminths and Human Welfare: *By Dr. Ben Dawes* 172

CHAPTER X
ABERRANT ANIMALS

Starfish, Sea-urchins, Sea-lilies and Sea-cucumbers 175
Beauty in Repetition: *By Dr. D. Dilwyn John* 183
On the Propagation of Echinoderms: *By Dr. T. Mortensen* 186

CHAPTER XI
ANIMALS OF UNCERTAIN ORIGIN

Phylum Polyzoa or Bryozoa . . . 189
Phylum Brachiopoda (Lamp Shells) . 191
The Animal and its Surroundings: *By Dr. Ben Dawes* 194

CHAPTER XII
PHYLUM MOLLUSCA

Slugs, Snails, Whelks, Mussels, Cockles, etc. 197
Giant Octopus and Squid . . . 214

CHAPTER XIII
CLASS CRUSTACEA

Crabs, Lobsters, Prawns, Shrimps, etc. 215

CHAPTER XIV
BIONOMICS

A Study in Overcrowding . . . 231
Different Ways of Living Together: *By Dr. Ben Dawes* 231
Form in Animals: *By Dr. Ben Dawes* 236
Crabs and their Methods of Defence: *By Dr. John P. Harding* . . . 238

CHAPTER XV
CLASSES PROTRACHEATA AND MYRIAPODA

Peripatus: a Zoological Curiosity: *By Dr. S. M. Manton, F.R.S.* 241
Relatives of Peripatus 244
Class Myriapoda: Centipedes and Millipedes 244

CHAPTER XVI
INTRODUCING THE INSECTS

Variations in Form 247
Aphides and their Enemies . . . 248
The Natural Fecundity of the Earth . 252
Class Insecta (Classification) . . . 253

CHAPTER XVII
THE INSECTS I

The sub-class Exopterygota: Cockroaches, Grasshoppers, Locusts . . . 259

The Termites: *By Dr. Thomas Elliott Snyder* 264
Lice, May-flies and Dragon-flies . . 269
Speed in Insects 272

CHAPTER XVIII
THE INSECTS 2

The sub-class Exopterygota: Land- and Water-Bugs, Cicadas, Aphides and Scale Insects 275
The Biological Control of Insects: *By Dr. C. H. Curran* 282

CHAPTER XIX
THE INSECTS 3

The sub-class Endopterygota: Lace-wings, Caddis-flies, Butterflies and Moths . 287
Protective Coloration in Insects: *By Professor G. D. Hale Carpenter* . . 298
The Senses of Insects 301

CHAPTER XX
THE INSECTS 4

The sub-class Endopterygota: Beetles . 303
Respiration in Aquatic Insects: *By Dr. G. Barendrecht* 312

CHAPTER XXI
THE INSECTS 5

The sub-class Endopterygota: Ants, Wasps, Bees 317
The Social Habits of Insects: *By Gilbert Nixon, B. A.* 329

CHAPTER XXII
THE INSECTS 6

The sub-class Endopterygota: Two-winged Flies 337
Parasitism in Insects: *By Gilbert Nixon, B.A.* 347

CHAPTER XXIII
THE ARACHNIDA

Scorpions, Spiders, Mites and Ticks . 351
The Jumping Spider: a Study in Behaviour 363

ACKNOWLEDGEMENTS

This is unquestionably the most pleasant page to write, for herein lies the opportunity to make some small return—a permanent record—for all the kindness and help received in the compilation of these two volumes.

To begin with I would express gratitude and appreciation to the authors, too numerous to mention individually, of all works consulted in the last three years. Next, I would hasten to thank my two friends and colleagues who gave both material and moral support in the early stages, Mr. J. D. Macdonald and, more particularly, Dr. W. E. Swinton, whose help and advice I have never sought in vain. I welcome especially the occasion for expressing my unreserved appreciation of the help given by Mr. F. Long, who has not only shouldered the bulk of the secretarial work but has been unflagging in his willingness to perform those many more menial tasks so essential to an endeavour of this sort. And, finally, a warm word of appreciation for Miss Jane van Kesteren, of Amsterdam, who was responsible for the lay-out.

Perhaps the biggest single task has been the collection and selection of the 1200 pictures illustrating these two volumes. The publishers, through their President, Mr. J. P. Klautz, gave invaluable help in the first instance by supplying some four hundred of those finally used. For the rest, I am particularly indebted to Mr Harold Bastin, for so many pictures used in volume 1, to Mr. A. E. Robins, Dr. Seget, Mr. Maurice Sawyers, Mr. W. S. Pitt, Mr. D. A. Kempson, Dr. S.M. Manton (for the beautiful coral-reef pictures), Kathleen Cooke, Professor L. B. M. Smith (for the picture of *Latimeria* on p. 128), the Zoological Society of London and the Trustees of the British Museum (Natural History), as well as to the many others whose names appear in the appropriate credit lines, and to some whose names do not.

My thanks are offered, also, to my friends and colleagues in the British Museum (Natural History) for advice and information, for help in writing the legends to the illustrations and in reading proofs (not to mention a hundred and one smaller services). Particularly to Dr. W. J. Rees, Dr. H. E. Hinton, Mr. Gilbert Nixon, Mr. R. W. Hayman, Mr. W. A. Smith, Mrs. Elliott, Mr. Derek Goodwin, Mr. Battersby, Mr. Palmer, Mr. E. Browning and Mr. S. Prudhoe.

Last, but by no means least, I would express my pleasure at the generous and ready response of so many American friends, previously unknown to me, who received

requests from me—'out of the blue'—for articles or photographs. Their names, are, for the most part, to be found in volume II, as authors or photographers, or both, and for this reason there is no need to particularize on the help received from the American Museum of Natural History, the New York Zoological Society, and, especially, the U.S. Fish and Wildlife Service.

The journey is nearly completed. Having crossed the Atlantic, I take a hop across the Pacific to extend the hand of friendship to my very good friend Professor Max de Laubenfels, and to thank him for his help and continued interest in the progress of this work.

London, 1949. MAURICE BURTON

INTRODUCTION

by

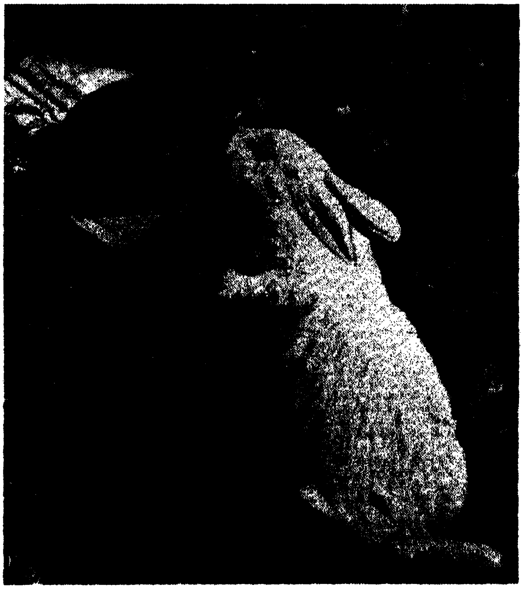
DR. M. BURTON

The importance of knowing about the world of living things

THE purpose of this book is to present knowledge of the living animals of the world, with particular reference to their behaviour in all its forms. For nearly a century past animals both wild and domesticated have been subjected to intensive study and the literature devoted to this is extensive. At first, the chief necessity was to evolve a satisfactory classification, and this together with the study of anatomy and physiology tended to attract the major attention, so that biology, the study of living things, and zoology, the particular study of animals, have at times been occupied more with dead things, in the laboratory and museum. There have been, however, at all times, those who sought to study the living animal in its natural environment, and their work has resulted, especially in recent years, in a desire on the part of more and more people to learn more about the behaviour of animals in their natural environment and to couple this with experimental work in the laboratory.

The time is ripe therefore to review our present knowledge of animal behaviour, against its necessary background of classification; and since both of these can only be fully understood and appreciated when related to the underlying evolutionary principles, it is proposed here to start at the beginning, with the simplest and lowest forms of life, with their elementary forms of behaviour, and trace their progression through the world of animals up to the apes and monkeys. Indeed, without we understand the reasons behind the simple habits of Amoeba, we cannot hope adequately to translate the complex behaviour of a chimpanzee.

The question may justifiably be asked: why should I be interested in the behaviour of animals? The answer is simple. To begin with, there is an intrinsic, or cultural, value in a knowledge of natural history, and experience has shown that there are few people who, if the information is presented in the right way, fail to find a real interest, even an excitement, in learning what goes on in the world around us. There are, however, the mere utilitarian aspects. Only through a mature understanding of natural history can we interpret in correct perspective the structure and function of our own bodies and minds. The science of natural history has, therefore, a major contribution to make in our striving towards human bodily and mental health, and our fight against disease. Moreover, the question of food supplies is far

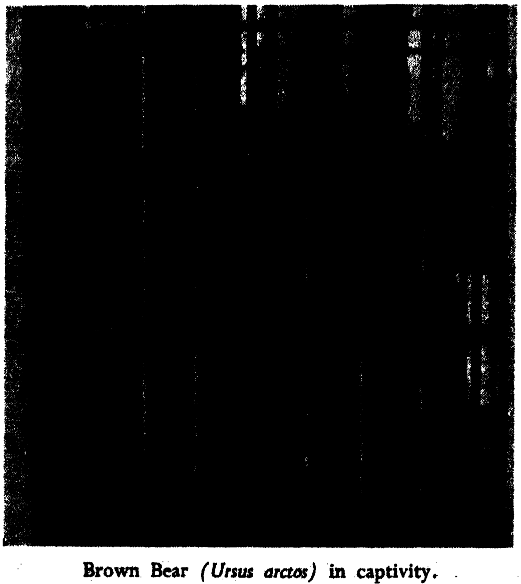


The white rabbit examines the black crow with a curiosity which the bird shows no sign of resenting. Life is often apt to be a very strenuous affair for wild animals, with bitter animosities and relentless killings, but it has its kindlier side which often results in strange friendships and actions as noble as any we normally associate only with human beings.

more closely linked with our understanding of the lives and behaviour of animals than is normally realised. Finally, while it is not suggested that a knowledge of natural history can solve our sociological problems, there can be little doubt that a better appreciation of human needs, both psychological and physical, and a better perspective of human potentialities and frailties, can be achieved against the background of an understanding of the natural laws of life.

The great advances made in the study of Natural History in the last hundred years have given everyone to-day the opportunity of knowing far more about the living world around us than was ever dreamt possible by our forefathers. True, we have failed to realise the dreams of the scientists of the latter half of the nineteenth century, to discover the origin and ultimate structure of living matter, although rapid advances are being made in that direction. But most people tend to be interested more in the behaviour of living matter, as demonstrated in the lives of plants and animals.

There are now few towns of importance which cannot boast a museum; and zoological gardens are everywhere increasing in number and efficiency. Yet the most skilfully stuffed specimen can impart but a meagre idea of the truly wonderful forces of creation and life activating the organism it represents. In the zoological gardens we can glimpse a little more of these; we can establish a sympathetic contact with the living animal itself. Yet even so, an animal in captivity is divorced from its natural surroundings and thwarted in the outlet of its natural instincts.



Brown Bear *(Ursus arctos)* in captivity.
We can know little of the real nature of animals kept in close confinement, except that they share with man the same emotion of melancholy.

The Muskrat *(Fiber zibethicus)*, native of North America, lives in the banks of rivers. Imported into Europe to be bred for its fur, it has escaped. Its burrowing habit threatens to convert large areas into swamp by undermining the banks of rivers. This is but one example of the damage caused by man's ignorance and thoughlessness of the world of living things.

To understand the deep significance of the vital life forces in all their manifestations, we must go into the wilds and, ourselves unobserved, patiently watch the unself-conscious behaviour of bird, beast and flower. This is, for most of us, a thing impossible of attainment, and in the following pages an attempt is made to bring together as briefly as possible some portion of the accumulated store of information concerning the living animals, their habits and emotions, their difficulties and triumphs, their battles with the elements, their dependence on each other, their loves, hates, desires, and the whole panorama of life in its most sincere and entrancingly beautiful form.

Before we can embark on this, however, it is necessary to traverse the stony path of explanation, and in the following introduction some of the technical aspects, essential for a clear understanding of our task, are enumerated.

THE MEANING OF ZOOLOGY

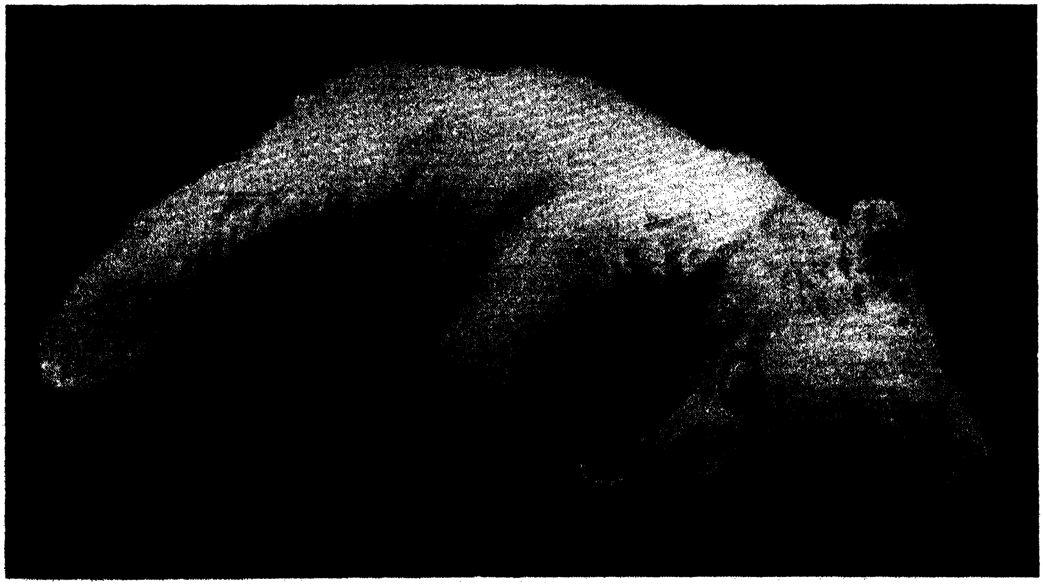
by

DR. W. E. SWINTON

Before beginning the study of any subject it is well to define precisely the nature of the subject itself and to determine the avenue or avenues which promise most pleasant access to it. The word Zoology is derived from two ancient Greek words, zoon, an animal, and logos, which may be translated as science. If we consult a good dictionary we will find that the term Zoology, this science of animals, is defined as "the natural history of animals, the science of their structure, physiology, classification, habits and distribution." Thus a zoologist is one who is familiar with the general substance of these various branches of the subject. Mere familiarity with the names of even a large number of animals will not make a zoologist, and the more one studies the wide fields of knowledge enumerated in this definition the wider one finds the field becomes and the more contacts with other sciences are observed. Some general knowledge of the sciences of botany, chemistry, geography, of geology, and of physics are found to be essential for any real appreciation of zoology.

Now, however forbidding this may seem it need not dismay or deter the student. It would not be a science if it were not capable of logical, or reasoned, treatment. If we examine calmly the field before us we shall surely determine some unforbidding and even inviting pathway towards its understanding.

When one looks around the world to-day it



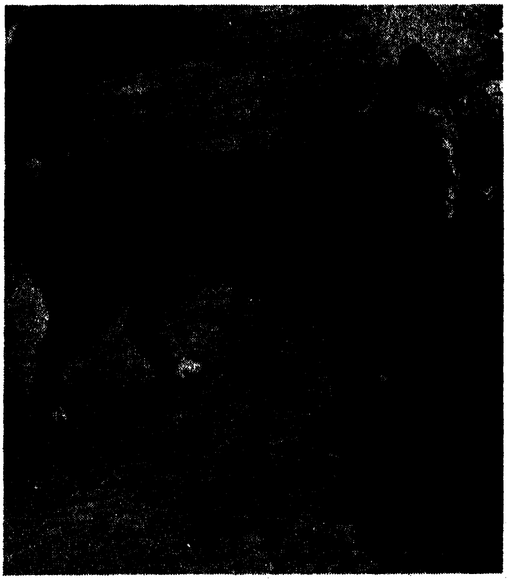
Snow White, a polar bear cub born in the Prague Zoo and brought up entirely among human beings. It became extremely sociable and companionable. Some animals are more easily tamed than others, but most so-called wild animals would be more tame than they are if man had not caused them to fear him. Travellers in regions uninhabited by man always remark on how little notice the wild animals take of them – until somebody fires a gun, or does something else to scare them. To a large extent, we have betrayed the trust our animal neighbours have in us.

Oystercatcher with its young.
One of the manifestations of life is the ability to reproduce; that is, to bring forth young which grow and become like their parents.

is easy to see that certain things are alive and others are not. Trees and flowers, birds and bees, our familiar dogs, horses, sheep and cows have one quality in common – they are alive. That is, they feel and they grow and they bring forth, in some way or another, young things which also grow and become like their parents. If they are treated in some ways this growth and reproduction may be hastened or increased; if treated in other ways they will lose these attributes, will become inert – they die.

Further, if we examine these forms of life which are briefly enumerated above they are found to be readily divisible into two classes. One, the plants, whose members derive food directly from the chemicals in the soil or from the air; the other deriving nourishment either from plants, or some parts of them, or from flesh, are known as animals. The majority of animals are not fixed but move freely over the ground, or in the ground, in the sea or in the air. The word animal is applied to all forms of such life, whether insect, fish, bird, reptile or mammal. By some authors it is restricted to those animals known as mammals, but this is illogical, confusing, and even bad English.

In the world of animals as it is known to most of us, one can readily visualize various branches of knowledge that must be subsidiary to the main term of zoology. We can all readily realize the immense numbers of different animals scattered all over the world on shores and in forests, in deserts and in lakes, in the seas and in the air, in caves and in trees, in the healthy atmosphere of the sunlit mountains and the pestilential atmosphere of the tropical jungles. The mere identification of these, the cataloguing of their occurrence and even the listing of their names is an immense task far beyond the power of a single individual. But various students in many countries have listed, and are still listing, the animals of their region so that it is possible for a scientist to have access to these lists and to survey superficially the magnitude of animal life. Such a survey reveals at once the desirability of understanding sufficient about the animals to grade them into classes; thus the beginnings of classification are brought about. Attempts at classification speedily show, however, that the superficial resemblance, or similarity of habit, of animals may mean little and certainly are not always guides to kinship. The birds, the bats, the insects, and certain reptiles and mammals, all equipped in varying degree

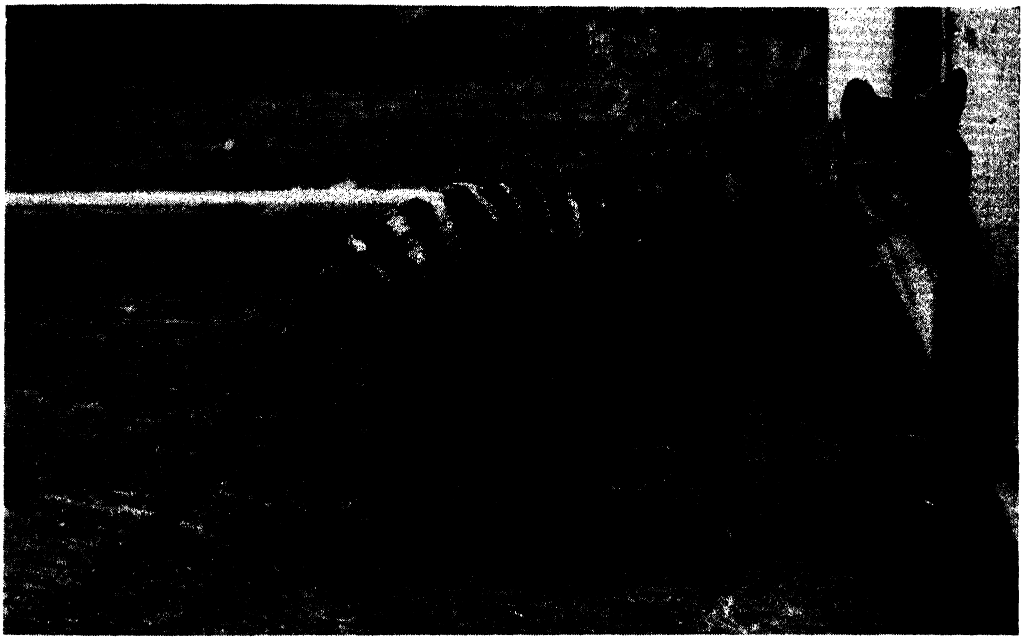


Dingo *(Canis dingo)* the wild dog of Australia, believed to have been introduced by man at an early period.

for gliding leaps, have certain similarities, sometimes fairly close resemblances. In the seas the fishes and the seals, the dolphins and whales show even closer similarities, yet we know that all these animals are of very different sort even if they live the same kind of life, in the same sort of place and at the same time. The true basis of classification rests upon something deeper than appearance and habit: it depends, we find, upon the underlying structure of the animals' bodies, so that it becomes necessary to understand the structure, or the Anatomy, and the working, or Physiology, of the body. This study of structure or form is known as Morphology.

We learn, however, that certain underlying anatomical characters are, in fact, sometimes accompanied by external features just as persistent, and we find, for example, that fishes always have scales, but never hair or feathers; that birds have always feathers but never hair or fish-like scales; and that mammals have hair but never feathers. Detailed study of animals tells us eventually which external characters are of importance and which (e.g. colour) are of less fundamental significance.

Physiology tells us how the animal eats, drinks, digests, breathes, breeds and so on, and in addition to helping us to understand the working of individual animals also sheds further light upon the significance of such features as size, colour, age variations, etc., and helps to explain many of the problems raised by the observation of the creatures in their natural haunts.



The Thylacine or Marsupial Wolf *(Thylacinus cynocephalus)*, also known as the Tasmanian Wolf. The Dingo and Thylacine bear a superficial resemblance to each other although there is no kinship, the first being a carnivore and the latter a primitive marsupial.

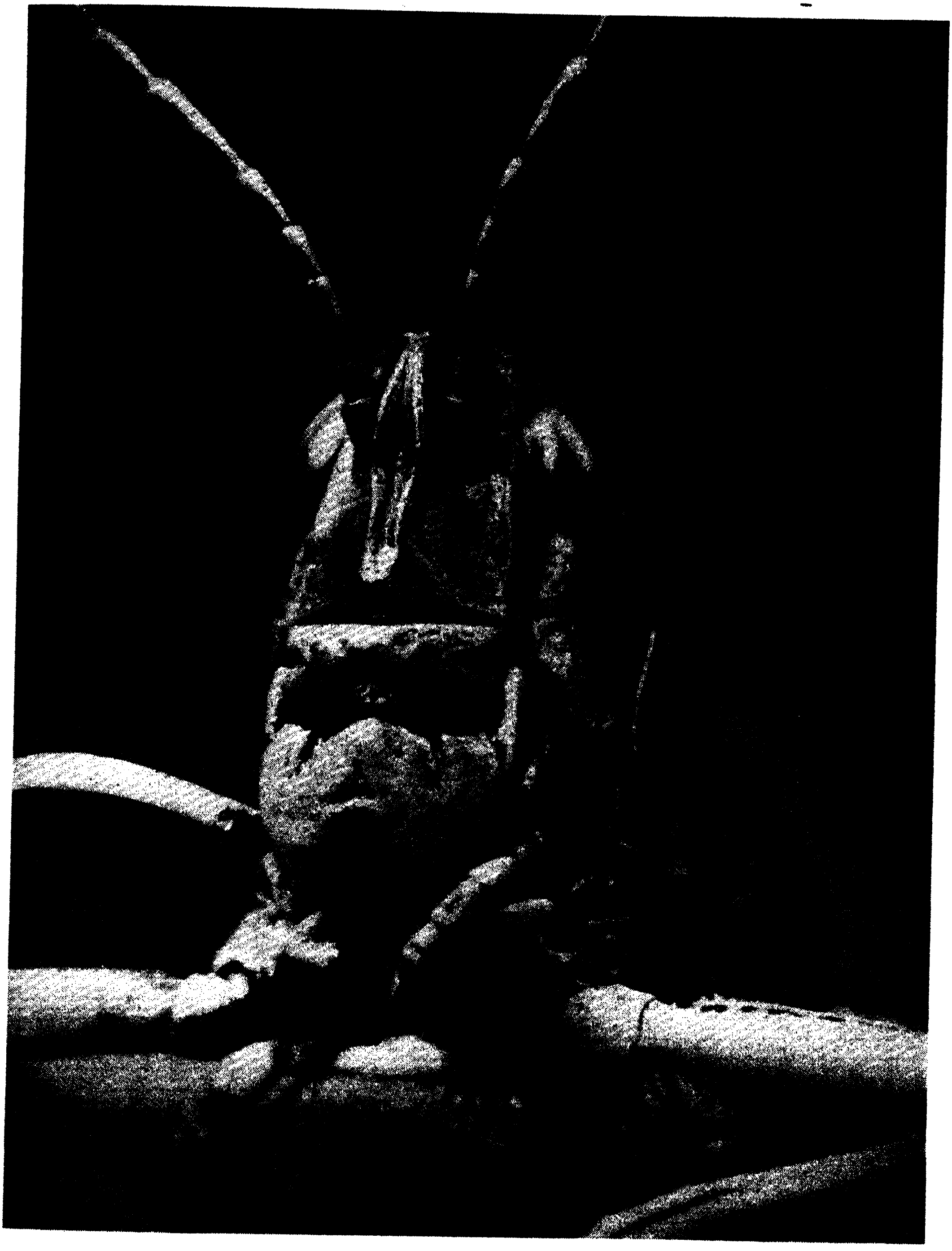
The life of an animal in its proper environment is, of course, one of the most attractive aspects of the science. It explains to us the habits of the animals, their food, their friends and foes, communal life and the highly important and, as we shall see, significant reactions of geographical factors, climate, etc., upon the group we may be studying. This study of animals and their natural background is generally called Natural History.

An understanding of the background calls upon Botany and Zoology, while the study of the distribution of animals and their reactions to geographical processes are known as animal geography, or Zoogeography.

In addition to these studies of animals themselves and their various modes of life there are of course important studies, indeed professions, concerned with animals which have grown up or developed within the last few years. For example, there is the work of the geneticist, who studies the development of the young and the inheritance of certain parental characters in them, a study of much economic importance, as will be shown later in this work. There are various persons, chiefly of medical education, who study animals as the causes or carriers of disease, and there are those who study the diseases of animals themselves, that is veterinary science. Enough has been said to indicate the vastness of the subject and the many branches that may prove attractive to a student or which may even provide him, after training, with an interesting livelihood, and further and authoritative information on these various aspects of Zoology is provided by specialists in the following pages.

A bull African elephant.
An elephant has keen sense of smell and, with a suitable wind, can smell a man from a distance of several miles. Its hearing is fairly good, too, but its eyesight is very deficient. In assessing behaviour attention must be paid to the development of the senses, for on these depends the animal's appreciation of the world around.

So far, however, we have been considering animals as an established feature of our everyday life, as an accepted and perhaps commonplace actuality, familiar in almost every habitable part of the world. Any serious student will be bound, before long, to ask himself the questions: How did these different animals originate?

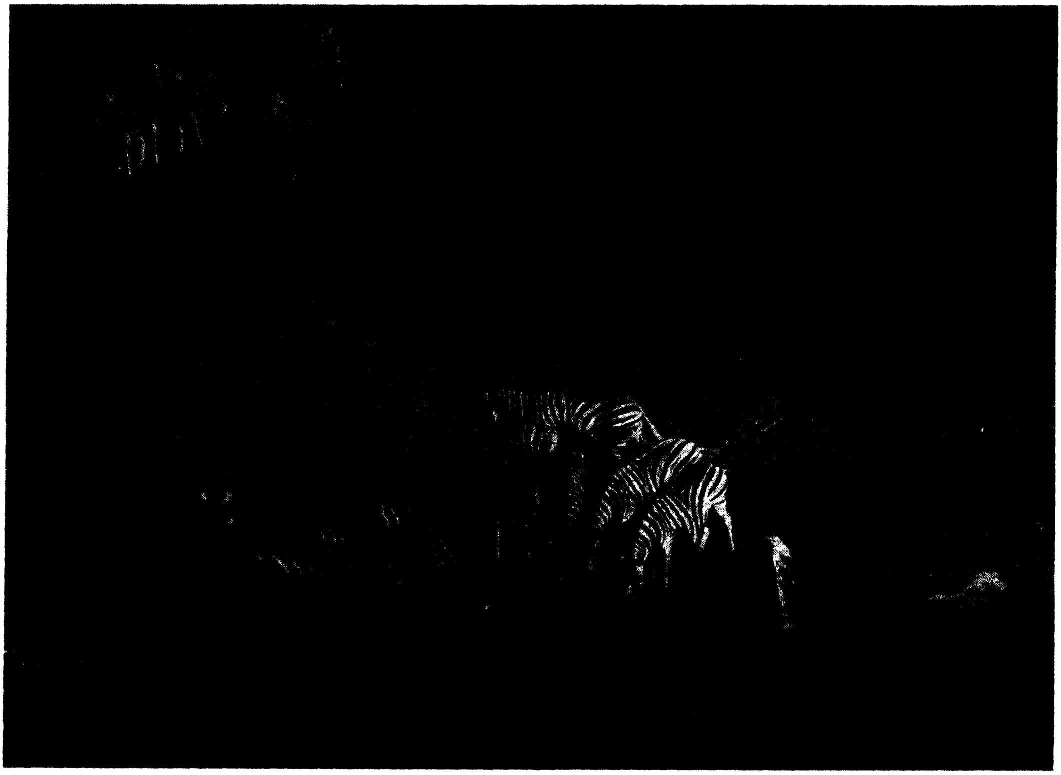


Close-up of the head of a grasshopper.

In spite, very often, of appearances to the contrary, all animals have an underlying similarity. Whether bird, beast or insect, whether large or small, the structure and habits have much in common, and it is in the interpretation of these that the zoologist unfolds a fascinating story.

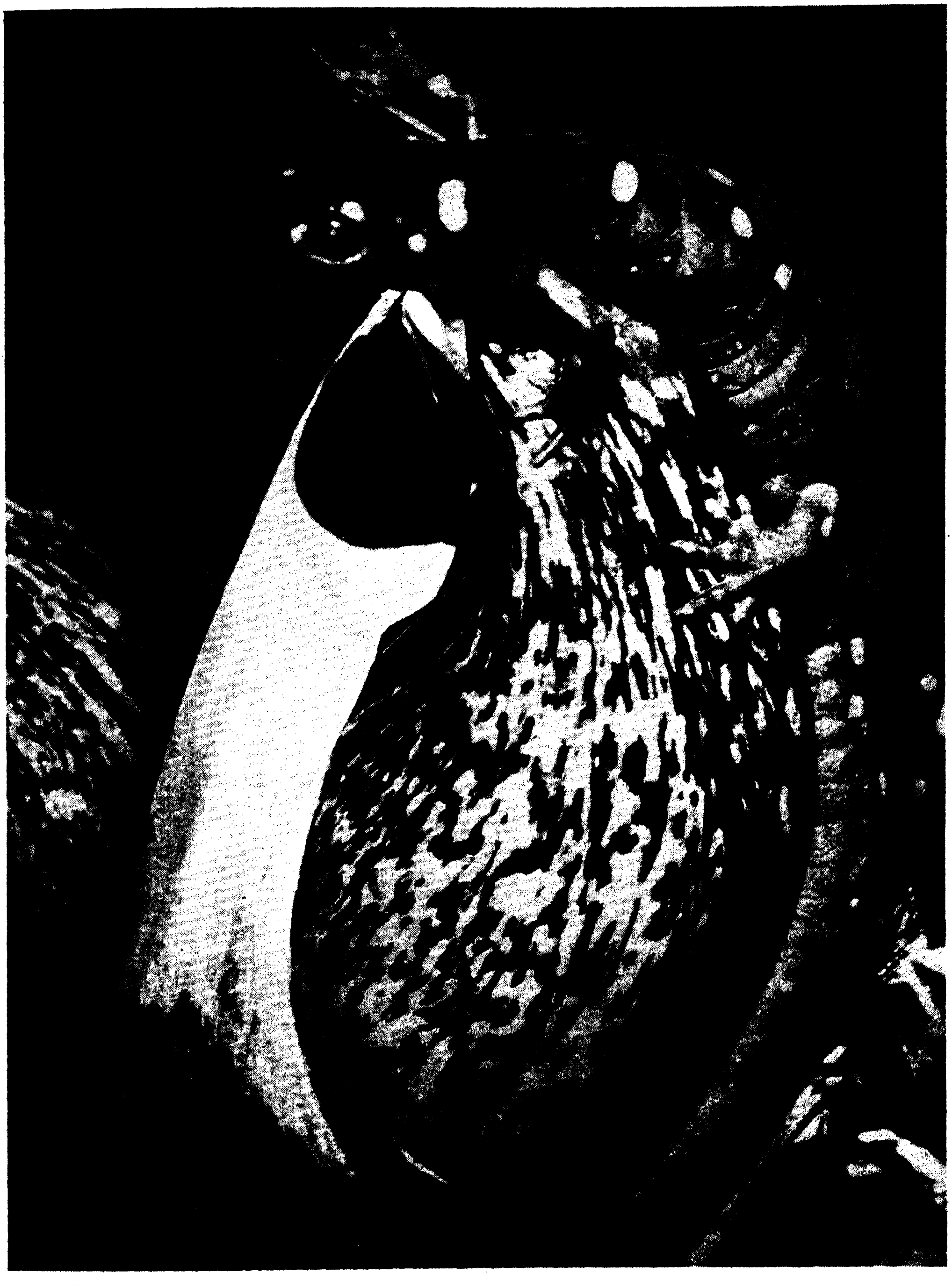
How did they become scattered over the world even to far-distant places? And how did life itself start on this earth?

For some hundreds of years inquiring persons in many parts of the civilized world had been familiar with strange objects, sometimes cast up on shores or at other times found by ancient cliffs or dug up in one way or another out of the ground. These objects were often made, apparently, of stone, and closely resembled fishes or other animals, some indeed looked exactly like shells or pieces of animals but were found where such things were not known to occur naturally. Some of these observers regarded their finds as quaintly shaped stones such as are frequently found to-day, and called them accordingly "lusus naturae", jests of nature. Others again who shared the current belief that mud and slime could generate living things thought that it was not surprising if the same sources gave rise to stony objects that had the superficial appearance of living things. Still others, an enlightened few, came to the conclusion that these were in fact the remains of once living creatures that had become petrified after death. Because they were discovered usually by being dug up, they were named in the Latin "fossilia" (i.e. things dug up) and this has now become shortened to "fossils". Fossils are the remains of creatures which were once alive but have been by some chance preserved from complete decay by such means as entombment, burial by some preservative earthy or rocky matter, by percolating waters with certain chemical properties and so on.



The struggle for existence has been the greatest influence determining the evolution of animals. The lion in its quest for food has had to become more and more agile and alert as the zebra, seeking to escape the lion, has become more and more watchful and speedy in running away. What will happen to animals in reservations, like these zebras and wildebeests in the Kruger National Park? Will the absence of competition cause them in time to degenerate?

Many persons thought, of course, that the fossils were the remains of animals destroyed in the flood, and even physicians of repute

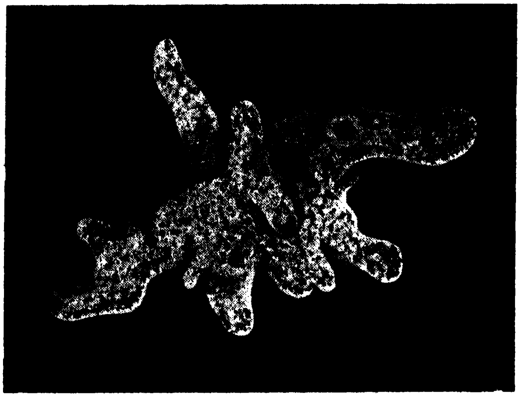


A Spotted Salamander on a skunk cabbage.

Newts and salamanders, with their relatives the frogs and toads, are a reminder of what happened in the Devonian period, when from fish-like ancestors were evolved the Amphibians capable of living both on land and in the water. The Amphibia of those distant times were much larger than those living to-day, and had much more heavily-built skeletons.

years ago have described fairly obvious portions of animals as the remains of human beings who perished in the Deluge. In the age of credulity the more remarkable the story, the better it was received.

With the passage of time, however, very many fossils came to be recognized, to be described and classified, and generally to be studied much along the same lines as that of living animals. This study became extremely well organized, and fortunately for our story many of the principal workers were men of wide knowledge of the zoology and anatomy of their time, keen and honest observers, and of philosophic habit. Particularly so can be said of those of the calm and expansive days of the Victorian age. About the middle of the nineteenth century an Englishman disturbed that scientific calm. His name was Charles Darwin and his bombshell was a highly important essay entitled *The Origin of Species by means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*. This work was of extraordinary importance, firstly for its true purpose in explaining the phenomena which had long attracted Darwin and in helping to understand the mechanism of certain fundamental life forces, and secondly in the stimulus to somewhat similar researches that it gave to other biologists. But it must be made clear that Evolution is not Darwinism, and that there is a very great deal of nonsense commonly believed and talked about Darwin by many people.



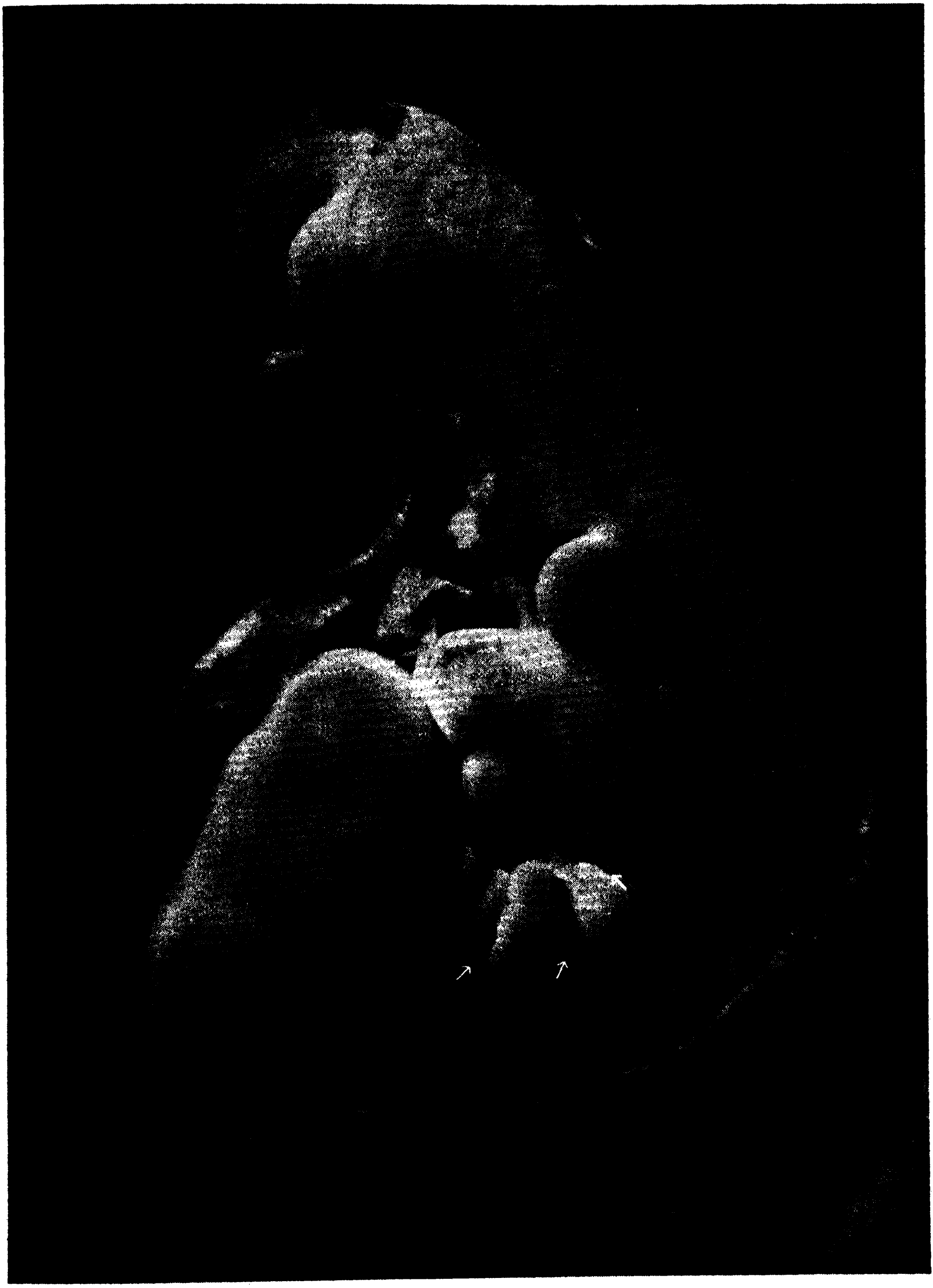
Fifteen hundred million years or more ago life first appeared on this earth. We do not know that the original looked like, but *Amoeba proteus*, figured here, is usually taken as the standard of primeval life, although we now recognise it to be a complicated, though primitive, organism.

The result of Darwin's stimulus to investigation on racial lines transformed the study of fossils and helped to solve many of its perplexities. In other words, the study of fossils became a Science, and the study of animal fossils is but Palaeozoology, the prelude to and the explanation of the varied and rich fauna of the world to-day.

Geologists can prove to us that the earth is not stable, but transitory: that the hills far from lasting for ages are changing; that the earth is but a frame bathed in immensity of time and ever presenting a changed picture. From canyon and cliff, from shore and railway cutting, from the bleak caps of mountains and the depth of mines come the grains of knowledge of the geological mills. Great numbers of fossils gathered from all over the earth tell us strange stories of the seas and lands.

Looking back down the long vista of Time we see a simple world devoid of any living thing. How life arrives we do not know. Perhaps, by some chemical process in the rich and muddy slime under the heavy atmosphere of primitive times, some fifteen hundred million years ago, the simple, unicellular, primal form of life appeared. We know nothing of it or of the physical conditions under which its earliest successors lived. This is partly because these little animals were jelly-like, without shell or skeleton that would be preserved, and partly because the rocks in which they might have been preserved are so old and crushed and worn by almost countless years. We do find, however, in the first period in which fossils are found that the forms of life are many and varied so that this hiatus in the geological record was filled with a vast and vital activity whose history, alas, is irretrievably lost.

For thousands of years the only forms of life were comparatively simple, shelled and unshelled, but without backbones, and all these forms were marine. Later on, the first backboned (vertebrate) animals were developed, but they were fishes and also of the seas. Not until comparatively late in the geological record, in the



All animals, and plants, show in their development traces of their ancestry. In this embryo of a chick of the domestic fowl can be seen the remains of gill-arches marked with arrows suggesting that its early ancestors breathed by gills like a fish. (Magnified 20 times.)

period in which many of the rocks of Devon were laid down, did the first backboned creatures invade the land. They were large and varied, but of a kind now only represented by the small and almost insignificant newts. They were amphibians, unable to live wholly without recourse to water-living conditions. It was in the succeeding geological period, the Carboniferous, when our modern coal seams were luxuriant forests and swamps, that these amphibians had their maximum development, but then the van of fresh invaders of a higher class, the reptiles, came upon the scene. We think of reptiles as only "creeping things", but many of the reptiles of the great period of middle life of the world, the Mesozoic, were far from creeping. For millions of years they were monarchs of the earth; the mighty dinosaurs on land, the bulky plesiosaurs and ichthyosaurs in the seas, and the soaring pterodactyls in the air. Had the reptiles produced nothing more than these they would be interesting and important, but they produced, too, the birds, and from some of the early reptiles in the arid days of the Triassic geological period there were born the mammals, destined to steal their leadership and ultimately, though indeed quite lately in the history of life, to produce Man.

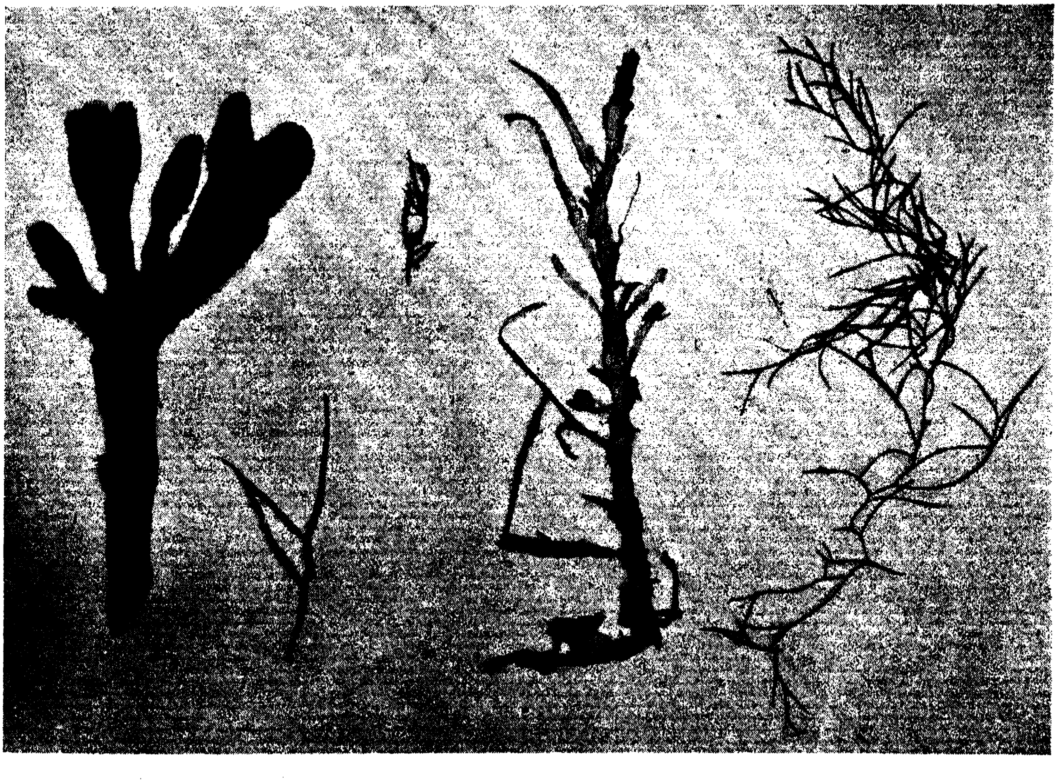
The long history of life that fossils illustrate is of unrivalled interest. We see the rise of once simple things to complexity and power: we see trial and apparently error, that groups seemingly destined to great things dwindle and fade, leaving no inheritance. In other words, the tangible evidences of the rocks reveal to us a true evolutionary story. This record is incomplete, like a cinematograph film whose beginning is lost, many of whose sequences are a little worn and hazy, and which is unfinished. Curiously enough we can verify some of this story by another scientific study. It has been known for some years that the young in their development recapitulate, very briefly, the history of their ancestry. Thus the human embryo at one period has gills, reminiscent of fish, and later a tail. This developmental history is brief and like our cinematograph film tremendously speeded up, but its value is obvious. The student of fossils, or palaeontologist as he is called, and the student of the development of animals, or embryologist, can between them make a well-authenticated story of the history of life. Looking at this long history we realize how impenetrably the roots of life lie hid from our knowledge, how long and well-developed was the stem that grew through the ages, and we realize more fully, more understandingly and in true proportion, the beauty, the significance and perhaps even something of the purpose of the leaves, the flowers and the fruit of that tree, which are the living animals we see in the fresh young world of to-day.

These attributes of our modern animal life are dealt with in appropriate order by the competent authorities in the pages that follow.

THE STUDY OF SYSTEMATICS OR TAXONOMY

The first difficulty which we encounter in considering the study of classifying animals, and one which epitomises many of the remaining difficulties, is the name given to the study itself. Among English-speaking peoples, the Americans speak of it as Taxonomy and English prefer to call it Systematics.

Anyone handling a large collection of things finds it necessary to classify them for convenience in handling: a librarian with his books, a stamp-collector with his stamps, a store-keeper with his stores, all need to divide their particular articles into a series of groups so that anyone of them can be readily identified or found. The system of classification used will vary according to the needs, and in dealing with animals it has been found most satisfactory to base this classification upon relationships. This is not, however, as simple as it may sound, and the system used to-day has been evolved only after centuries of study. Even so, although zoologists are agreed as to the main principles and the larger groupings, there still remain disagreements as between workers in the same field and between the arrangements used in different countries. Consequently the non-



Many animals closely resemble plants in general appearance. On the left is a sea-mat (Phylum Polyzoa, or Bryozoa p. 189), and two sea-mosses; next to them is a seaweed and on the right is another sea-moss (see p. 149). All natural size.

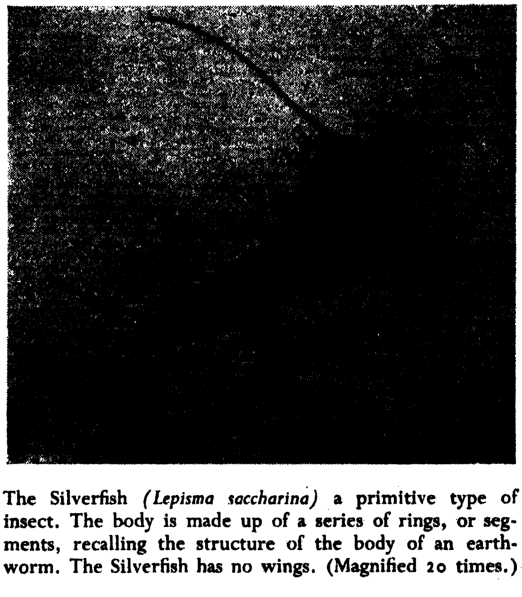
A bat contrasted with a Giant Water Bug. The wings in each case perform the same function but have a different origin. They are, therefore, analogous organs and not homologous.

scientific reader is apt to be somewhat bewildered by the differences found in passing from one book to another. For this there is no simple remedy, but it does reflect the idea that although the most logical classification of animals is one based on their relationships, these relationships are by no means always clear and may often be very obscure.

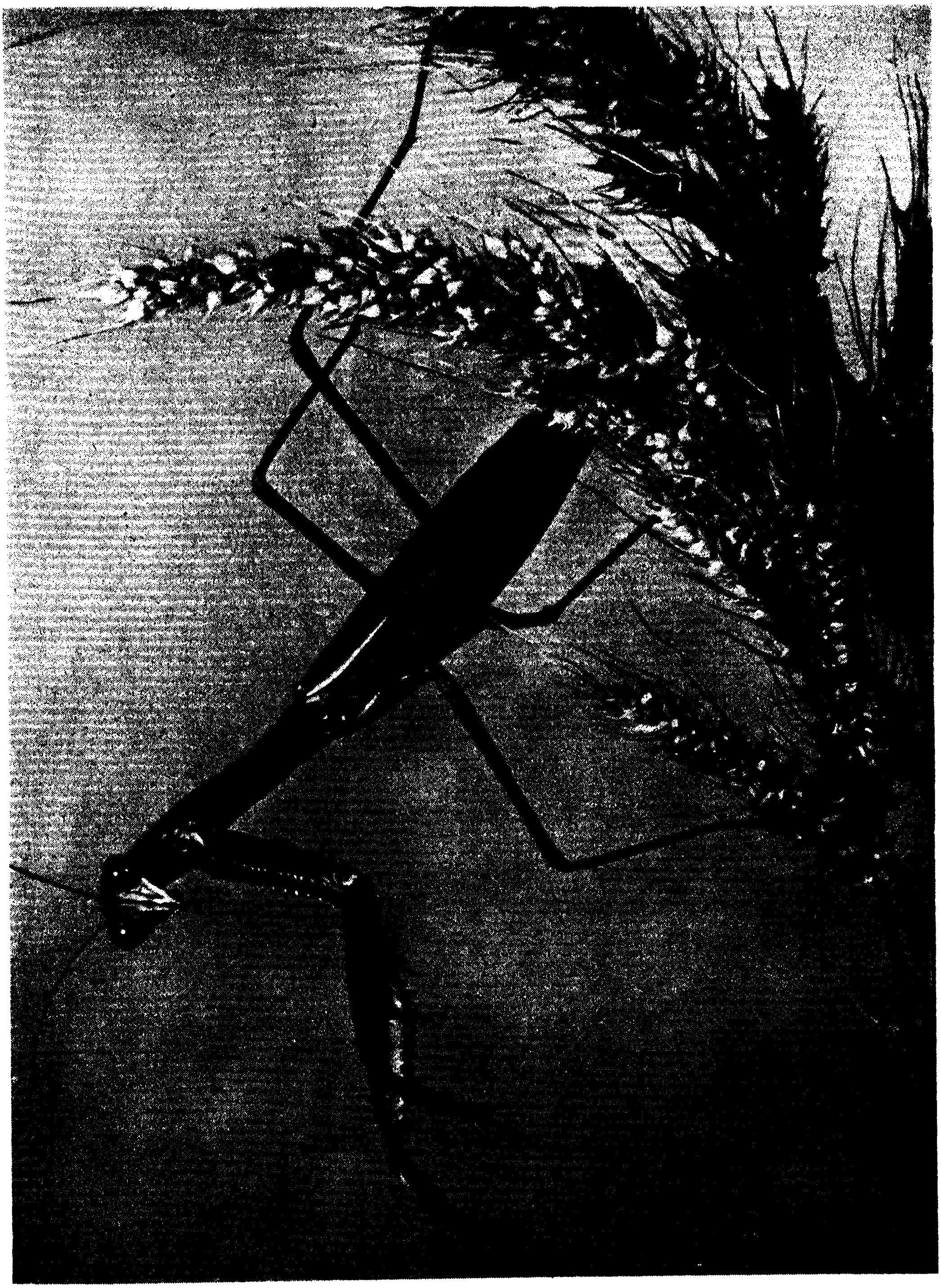
The first advantage obtained from basing the classification on relationships is that when it is expressed as a diagram it becomes a genealogical tree and the evolutionary lines of development are clearly exposed thereby. Whoever has in his mind a fairly plain impression of this classification can relate subsequent knowledge to the general evolutionary principles.

In order to know how relationships are assessed it is necessary to be clear as to the meaning and use of a few words which constantly recur in any zoological discussion. The first pair of words includes *primitive* (derived from the Latin *primus*, or first) and *specialised* (Latin *specialis*, from *species*, a particular sort, kind or quality). Thus a primitive animal is one which has departed little from the common ancestor of the group to which it belongs, while a specialised animal has departed widely from it. As often as not the common ancestor is unknown to us, but it is possible to arrive at a reasonable assessment of what it may have been like by a process of reasoning and deduction based largely on geological evidence. In other words, by comparison with what is known we trace backwards through stages which have to be guessed. Consequently we often read of a hypothetical ancestor. A good example among insects is afforded by the Silver-fish and the Praying Mantis. Both are insects, but the first is very near to what we imagine the ancestral insects to have been, and the second is highly specialised in its habits and particularly in its method of catching its prey.

The next pair of words is *homologous* and *analogous*. Homologous organs are those which are derived from a common ancestral organ, although they may not now have either the same structure or function. Analogous organs are those that have a superficial resemblance to



The Silverfish *(Lepisma saccharina)* a primitive type of insect. The body is made up of a series of rings, or segments, recalling the structure of the body of an earthworm. The Silverfish has no wings. (Magnified 20 times.)



A Praying Mantis, looking like some prehistoric monster, is a good example of a specialised insect. The body is elongated and the front pair of legs are highly modified to form a living trap for the capture of other insects on which the Mantis feeds.

The Californian Sea-Lion *(Zalophus californianus)* is closely related to the terrestrial carnivores such as dogs and wolves. It has become adapted to an aquatic life, and its four limbs converted into flippers. The tail has almost disappeared and is a good example of a vestigial organ.

each other but perform the same or similar functions while having a different origin. The wing of a bird and the front leg of a horse are homologous as they have the same essential structure which they owe to inheritance from a common ancestor, but the one is used for flying and the other for walking. On the other hand, the wing of a bird and the wing of a butterfly are analogous since they bear a superficial resemblance to each other which they owe, not to a common ancestry, but to adaption of fundamentally different structures along similar lines for similar functions.

Another pair of words over which confusion often arises includes *vestigial* and *rudimentary*. An animal often possesses traces or vestiges of organs which have ceased to be any use to their owners yet which persist with remarkable pertinacity. The whale, descended from a terrestrial quadruped, has lost its hind-limbs, yet it still has the remains of a hip-girdle,

Neoceratodus forsteri, The Australian Lungfish.
The swim-bladder, normally a hydrostatic organ, found in many fishes has taken on partially the function of a lung in *Neoceratodus* and its relations. In this case, then, we have to deal with a rudimentary lung.

reduced to a few slender and useless bones. Rudimentary organs, on the other hand, are those which are only just beginning to arise. Here it is not possible to give such a satisfactory example for the simple reason that while it is relatively easy to trace backwards stages that have already been reached and passed, it is not so simple to look at a particular organ and say what it will have developed into a million years hence. The pigmented organs, responsive to light, found in many worms can, however, be compared with the simple eyes of molluscs and referred to, with a fair degree of certainty, as rudimentary eyes.

Another phenomenon connected with vestigial organs may be mentioned. This is *atavism* or *reversion*, by which is meant the sudden and sporadic appearance of an ancestral structure which had been completely lost or very greatly reduced. All human beings bear at the base of the spine a group of bones, the coccyx, which represents all that is left of the tail which our ancestors are believed to have possessed. Occasionally a baby is born with a free and

The Bee Louse *(Brauta coeca)* is a minute, wingless fly; its ancestors had wings, but these have been lost as a result of its parasitic habits. The Bee Louse is secondarily wingless; and, from the point of view of flight, is degenerate. (Magnified 20 times.)

Cephalodiscus longstaffi, from the Antarctic, belongs to the Protochordates, believed to represent the forerunners of the Chordates (= Vertebrates). *Cephalodiscus* appears to be degenerate and consists of colonies of primitive Chordates living in a common, horny compound or investment. (Natural size.)

undeniable tail several inches in length. Similarly, the leg of a horse is derived from an ancestral limb having five digits like our own hands, but in all normal horses only the central digit is left, greatly elongated, and the vestiges of the bones of two other digits. Very rarely, however, a reversion appears in which a horse has three digits, or even five, as in the famous case recorded by the elder Pliny.

Finally, we must be clear on the words *degenerate* and *secondary*, both of which are closely connected with the last pair of words discussed. A degenerate organism is one which has departed from the specialisation enjoyed by its ancestors and the state in which it finds itself is said to be secondarily acquired. To return again to insects, the Silverfish is primitive and flightless, but a flea is specialised and flightless. Whereas the ancestors of the Silverfish did not possess wings, those of the flea did. The flea's flightlessness is, therefore, secondary because the ancestral wings have degenerated and are lost.

Although it has been possible to deal in a brief manner with some of the difficulties confronting the student of animal relationships, sufficient has been said to show that the subject has many complexities and that in natural history as in everything else "things are not always what they seem."

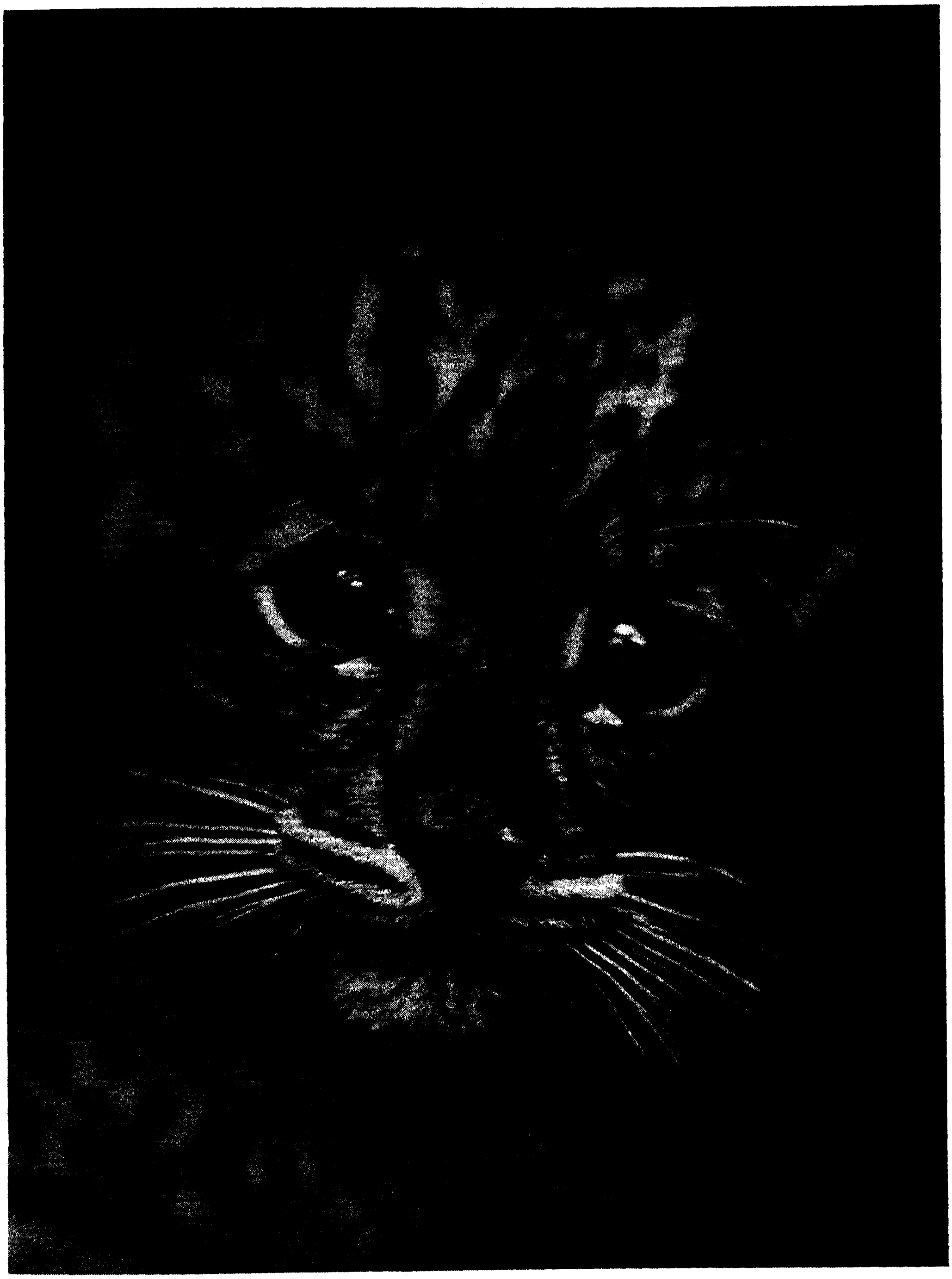
In classifying animals, then, they are placed in groups which are repeatedly sub-divided in such a way that the final grouping and subdivision accords closely with the actual course of differentiation during their evolution. Thus, the Animal Kingdom is sub-divided into a number of groups, each of which is called a phylum; and before proceeding further it will be necessary to explain that it has been the custom formerly to divide the Kingdom into two comprehensive groups, the Invertebrates and the Vertebrates, which have been referred to by some authors as sub-Kingdoms. While these two can still be loosely used, and conveniently so, it is well to emphasise that many animals included in the so-called Vertebrates do not possess vertebrae, namely the Protochordates. Yet other authors get over this difficulty by treating the Vertebrata as a subphylum of the Phylum Chordata (which includes all Vertebrates and also the Protochordates).

Perhaps the clearest way of indicating the successive stages of subdivision will be by reference to the species to which we belong.

Kingdom - Animalia (all animals).
Phylum – Chordata (animals with an internal skeleton based on a cartilaginous rod, the notochord, which may or may not develop into a backbone).
Class – Mammalia (warm-blooded Chordata having the body coated with hair and suckling their young).
Order – Primates (including Lemurs, Monkeys, Apes and Man).
Family – Hominidae (including fossil and modern Man).
Genus – *Homo* (including all races represented by living men and some species now extinct).
Species – *sapiens* (all races represented by men now living).

The ultimate name by which an animal is known consists of two parts, the generic name (in the case of man = *Homo*) and the specific name (= *sapiens*), and this system of nomenclature is called binominal.

It is often objected by the non-scientific reader that in using Greek and Latin names the scientist is being unnecessarily obscure. The questions are asked: Why must you speak of *Felis domesticus* when we have a perfectly good word, cat, which everyone understands? Why not use the common names? The first point overlooked is that by far the greater number of animals have no common name and never could have. Secondly, science is international and an agreed name like *Felis domesticus* has an international value whether the reader is an Englishman, Russian or Chinese. Thirdly, common names can be confusing themselves, as for example *Pagrus unicolor* of Australia and New Zealand. This is called a cock schnapper when young; when it weighs about a pound it is red bream; when larger it is squire or school schnapper; when full grown it is countfish; when very old and large it becomes the native, or rock native or old man schnapper. Eight common names for the same fish!



Portrait of a young Leopard.

Young animals remind us of the age-old speculations on the origin of life. In the higher animals there is no question that life is generated from existing life only, but the ancient philosophers believed in the spontaneous generation of life, that fleas and lice were developed from dirt, that eels rubbed themselves against the rocks and that particles of skin came away and formed young eels, and so on.

TABLE OF CLASSIFICATION FOR THE ANIMAL KINGDOM

					Estimated number of species now living
Multicellular Animals or Metazoa	Triploblastic Animals	Vertebrates or Chordates		Man	
				Mammals	4,000
				Birds	15,000
				Reptiles	4,000
				Amphibia	2,000
				Fishes	15,000
				Protochordates (A group of doubtful affinities standing between the Vertebrates and Invertebrates, and perhaps bridging the gap)	2,500
		Invertebrates	Arthropoda	Arachnida	30,000
				Insects	800,000
				Myriapoda	8,500
				Protracheata	60
				Crustacea	20,000
				Mollusca	80,000
				Brachiopods	140
				Polyzoa	4,600
				Echinoderms	5,000
				Worms	20,000
	Diploblastic Animals			Coelenterata Jelly-fishes, Sea-Anemones, Corals	7,000
	Sponges or Porifera (probably best regarded as colonies of Protozoa)				5,000
Unicellular Animals Protozoa or Protista					20,000

CHAPTER I

THE ORIGIN OF LIFE

THE OBSCURE PAST: WHEN AND HOW DID LIFE BEGIN?

by

DR. W. E. SWINTON

ONE of the problems that have confronted all thoughtful men for many years has been the origin of Life, the date and place of its inception, and the processes that were involved. It is of its very nature insoluble but like many such problems its consideration is full of interest and its speculations are not merely idle.

Explanations in the past have been fantastic or scientific, both being often quite unhelpful. The ancient philosophers believed implicitly in a plastic force inherent in the very basis of matter. They were familiar with the remains of once living things that had become petrified or fossilized, and regarded these as similar in appearance to the things now living around them. They postulated that they had been formed and developed from this plastic force in the soil or rocks and that, instead of escaping from their earthy confinement and taking their places among truly living things, they had remained imprisoned and had developed stonily in their subterranean fastnesses.

Such famous physicists of the nineteenth century as Kelvin and Helmholz suggested that the original germ of life, whatever that may have been, was borne to our earth from another planet. It might have been conveyed through, and have survived the hazards of, interstellar space in some cranny of a meteorite; or it might have been borne on the invisible wings of light pressure, the force of the sunlight that makes the vanes of a Crookes' Radiometer revolve. This latter hypothesis is, of course, feasible, but does not solve the problem, it merely refers it back. Fortunately for our investigation there are one or two more positive lines of approach.

As we trace the history of fossils (see p. 58), we pass from the age of men to mammals; from the time of mammals to that in which the dominant forms were all reptiles, back through an amphibian age, past the conquest and occupation of the lands, to the fishes and the invertebrate animals in the sea. We can trace the marine history back almost to the beginnings of geological times, where the earliest forms are shell-less, marine, simple animals and plants of a kind quite like those we call the Protozoa and the Algae (seaweed) to-day.

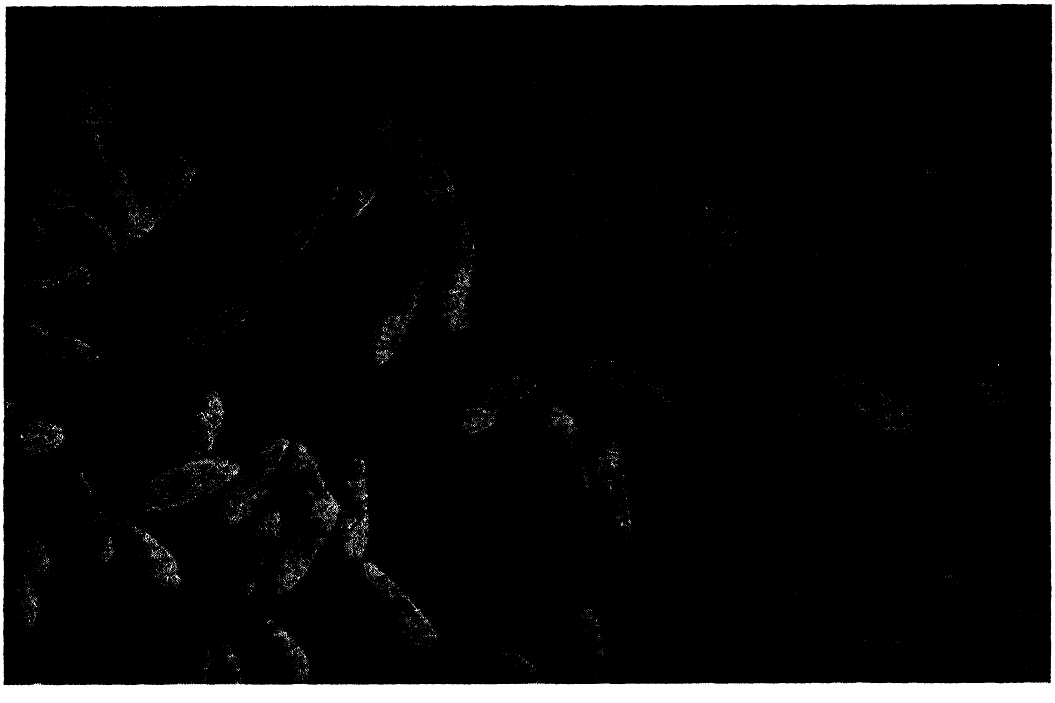
Two bacterial cells being attacked by a bacteriophage (or virus) the particles of which enter the bacterial cell, multiply prolifically within a few hours and cause the disintegration of the cell. By means of the electron microscope smaller and even smaller particles can be seen. The diameter of the bacteriophage particles is 0.00005 mm. *(Photograph by courtesy of S. E. Fusia, M. Delbrück and T. E. Anderson, from Journal of Bacteriology: Williams and Wilkins Co.)*

We can thus argue reliably that the earliest forms of life were closely akin to, or were fairly soon developed into, these simple unicellular things. The microscope helps to confirm this view, for whatever kind of living tissue we examine we can determine that it is composed of unicellular units, essentially similar to the one-celled independent forms of life.

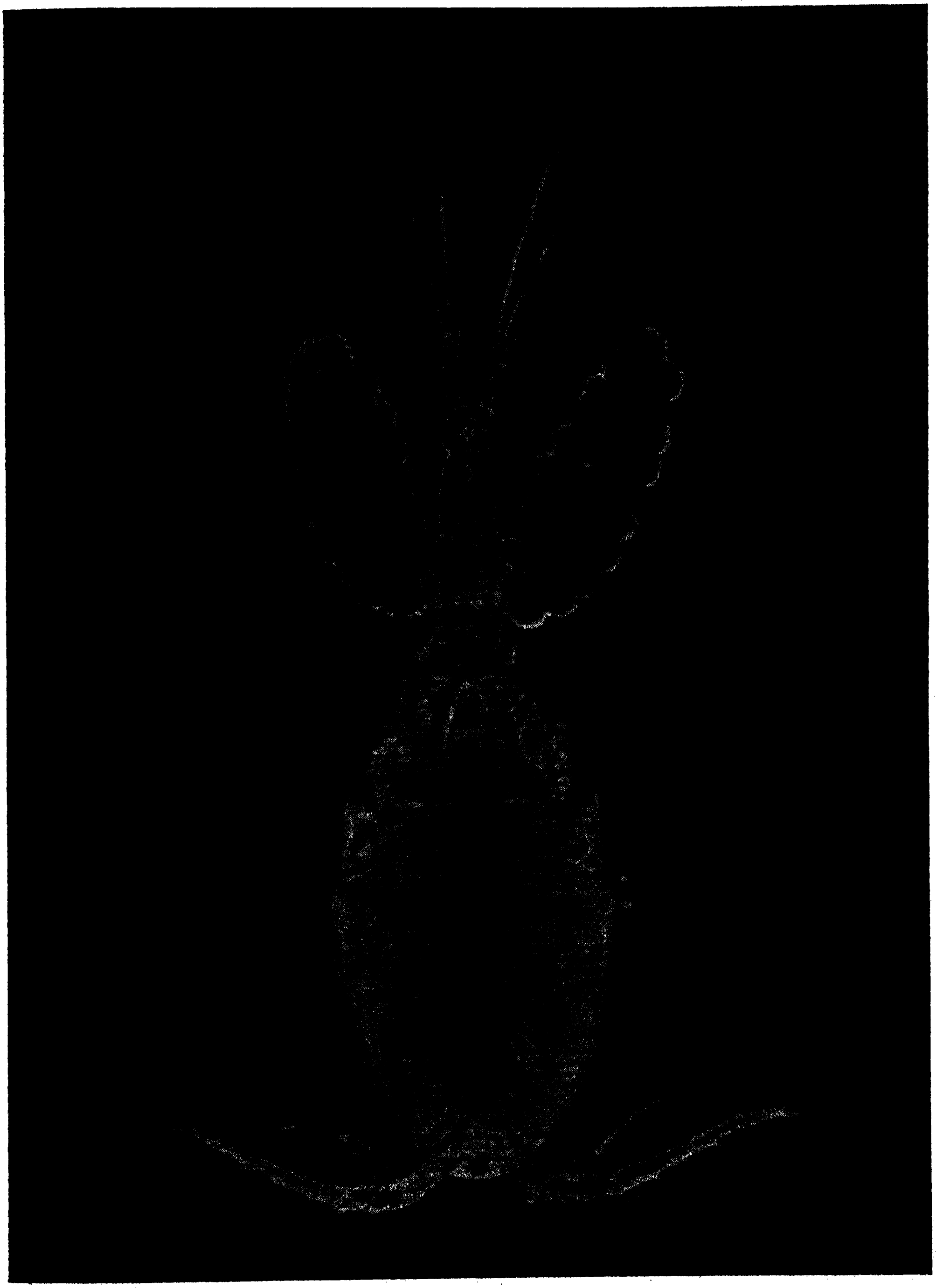
It is therefore logical to turn to these units for further information if we want a more precise estimate of Life's essential nature. Now we can watch the simple forms alive in the laboratory, and that helps to tell us how they feed, grow, and multiply, but it does not explain their composition. Can we analyse them equally well in the laboratory? We can find out their chemical make-up, but once we start this chemical investigation we have killed them and are merely analysing the materials of dead protoplasm.

Yet this is not entirely misleading or uninstructive, for we find that the materials of these simple organisms are closely similar to, but more complex than, substances that can be prepared nowadays by the chemists. These are the fats and carbohydrates, and the more complex proteins. All are essential constituents of food, but food in animals is not merely an aid to living, it is the very foundation of the cells of which they are made. They are also known as organic substances and all contain Carbon, Hydrogen and Oxygen.

If we return to the past it is possible to visualize the earth before life. The seas, the heavy atmosphere with its gases, the heated, or at least still cooling earth, provide a background rich in chemicals, especially Carbon, Calcium, Phosphorus and their compounds. Now we know that chemical combination is facilitated when two or three media are in close association—here the solid earth, the liquid seas, and the gaseous atmosphere—and especially under the influence of heat and possibly ultra-violet rays (from the sun). All these conditions we know were once present. It is not unlikely that at some particularly favourable moment a substance that we now call a catalyst, something which actuates processes, but is not itself involved, rather like a trigger firing a gun, may have set off the primary chemical experiment that resulted in a little greyish froth being formed on the water. Its very nature would make it adhere as a rounded blob; its outer surface would be tenuous but coherent (like that of many non-living chemicals) and would allow



A swarm of *Paramoecium*, a microscopic animal found in stagnant pools. (Magnified 20 times.) The invention of the microscope enabled the search to be carried into even more inaccessible fields, and always it was found that life was generated from life; nowhere was it found to arise spontaneously from non-living material. *(By courtesy of G. B. Instructional Ltd.)*.



The Crustacean, *Cyclops*, one of the water fleas, with a prominent pair of egg sacs. When ripe the eggs are discharged and fall to the bottom of the pond, into the mud. The pond may dry up for weeks, but when the water comes back the eggs hatch and *Cyclops* appear again as if by magic. It was such things that strengthened belief in the spontaneous generation of life, it being believed that *Cyclops* and the like grew out of the mud itself. (Magnified 65 times.)

fluids and air and, most important perhaps of all, the sunshine to pass through it. This would be the first living blob, destined to grow and, from the physics of its shape, to divide when it reached a certain limit. Time was the remaining factor necessary in its elaboration, and here science sees no difficulty. It is almost certain that nearly a thousand million years passed before the primitive bubble had developed into the very simplest form of life that we can detect today.

THE VIRUSES: A BRIDGE BETWEEN THE LIVING AND NON-LIVING

by

DR. W. E. SWINTON

It is obvious that neither mice nor men are spontaneously generated, nor are they derived from other kinds of life. They are definitely derived from adults almost precisely similar to themselves. This is true also of all the creatures whose life-history can be studied with or without the microscope, including the Protozoa and the Bacteria. There is, however, a group of very small, apparently living things, probably allied to the bacteria, of which it is not easy to be so definite. These are the viruses. The name is derived from the Latin meaning a slimy substance or a poison. Ordinarily they are known as the filterable viruses because most of them are so small that they pass through the finer filters used in a bacteriological laboratory. Some of the largest viruses can just be seen in the ordinary microscope and appear to be like the bacteria, but most of them remained invisible and known only by their effects until the invention of the electron microscope.

Chromium shadowcast Electron micrograph of the particles of influenza virus type B (formalized). The particles are about 0,00012 mm. diameter.
(Courtesy of Duke University Medical School, Department of Experimental Surgery.)

This new aid to science allows these tiny things, usually to be measured in millionths of a millimetre, to be seen but it does not explain them. The problems they raise are of more than academic interest, for many of the most troublesome diseases affecting the human race are of virus origin; e.g. colds, influenza, infantile paralysis, smallpox, mumps, measles and yellow fever.

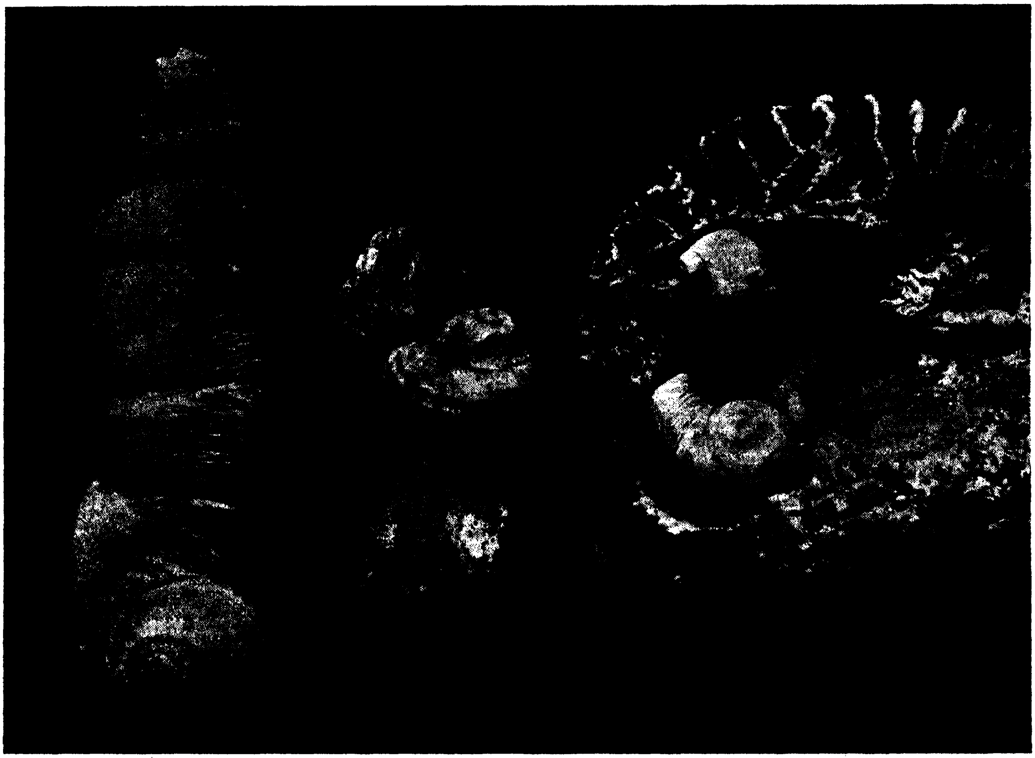
Within recent years there has been much discussion whether the viruses are actually alive, and the question has not yet been answered. Quite recently there has been shown in London a crystalline virus that is carried by flea beetles and affects plants. Its constitution has been observed almost as if it were an inorganic crystalline substance.

The viruses have been called non-living, and it has been suggested that even if the largest of them have similarities with the bacteria this need not apply to the smallest. It has been suggested that they have been derived from dead matter even if they themselves are now living. Another theory is that they are fragments of truly living things that have been disrupted (viz. that they are genes from a cell) but that by chance they have found themselves in new surroundings in which they can continue to live. It is not easy to answer all the questions raised by these theories, for viruses have not so far been cultivated in the laboratory in the way that most bacteria can be. They grow only in a living cell. Thus for many years all that was

A polar bear has a coat of long hair to protect him from intense cold.
Life is the expression of an interaction between an animal and its environment, and the chemical processes involved, operating over countless years, are responsible as much for the simple habits of microscopic organisms as for the more highly-organised structures and habits found in the larger animals.

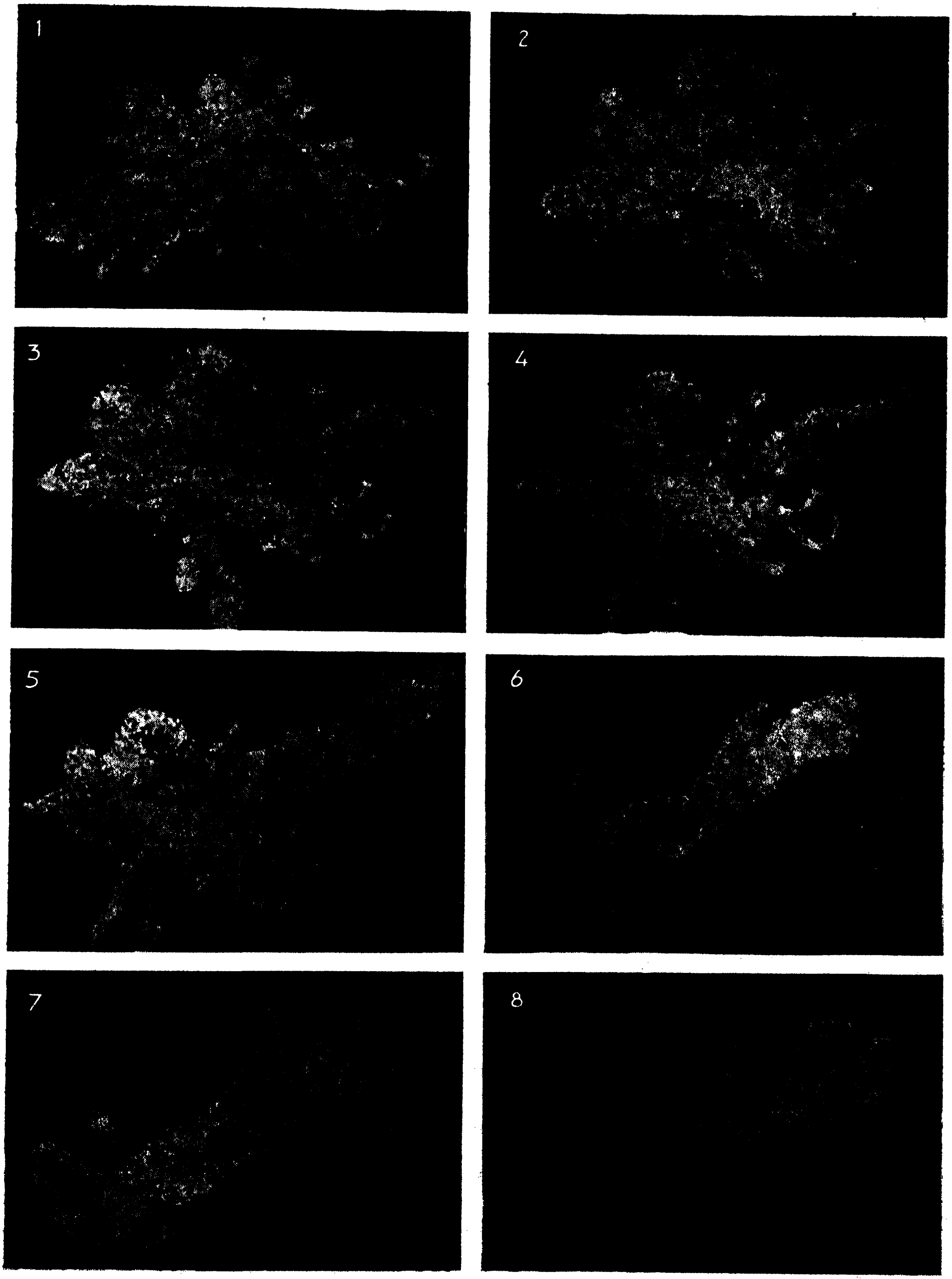
definitely known about them was their smallness, that the filtered material containing them if injected into animals would have fairly constant results according to the nature of the strain, and that they were selective in their effects upon the victim. That is, one kind would affect the skin, others the lungs, the central nervous system, and so on.

Quite recent work tends to show, if it has not actually proved, the essentially similar nature of viruses. They all appear to be alive and all seem to be derived only from living viruses. Further, it would appear that they are not simple or primitive organisms. It is known that the chemical properties of some are exceedingly complex but most, if not all, seem to be parasitic forms of life, supplied with the bare anatomical and physiological apparatus for their continuance if they can obtain food and shelter elsewhere. This is why they are a menace and an anomaly. When they settle in the cells of a host, their presence causes disease, yet it is in the interest of the virus itself that the host should not die, for thereby they are deprived of home and supplies, and ultimately of their life as well. Experience would seem to show that in many cases some form of balance between the virus and its unwilling or unwitting host is being struck, that in course of time they achieve a harmony, but one that may be disturbed if the general level of health, that is resistance, in the host becomes lowered. This uneasy partnership may result in some cases in the adult human being becoming a carrier. While able to maintain his own health more or less satisfactorily, he can transmit the specific to those (strangers to the locality or children) who have not had the opportunity of gradually acquiring a similar immunity.



A markedly physical reaction to environment. A Mollusc from the Red Sea and Indian Ocean which lives in coral-masses. At first the shell is normal but as the coral grows the mollusc, to avoid being enclosed in it, lengthens the shell to keep pace with it. The mollusc lives in the front part of the shell.

Thus it would appear that we must regard the



Amoeba proteus, the text-book standard of the simplest form of life.
The series of eight photographs taken at intervals shows the irregular outline of the animal when in active movement. A number of pseudopodia are pushed out, but gradually one of them becomes predominant and determines the direction of movement. The manner in which the body flows into the foot is also clearly seen. (Magnified 200 times.)

viruses as minute but complex forms of life, possibly degenerate, but certainly not the focal point of the structure of life nor the bridge between the living and the inorganic worlds.

THE FUNDAMENTAL NEEDS OF LIVING MATTER

The fundamental constituent of both plants and animals is protoplasm consisting of chemical compounds of very complex structure, composed of many elements and having a large amount of potential energy locked up in it. The body of any plant or animal not only undergoes destruction after death; in life, it is constantly being destroyed and as constantly renewed. Thus, every organism is continuously seeking to safeguard itself against the destructive influences of the environment; life is the expression of a constant interaction between the living organism and its environment. This is of fundamental importance to be constantly borne in mind, for through it we can the more readily interpret the otherwise bewildering variety of animal behaviour.

Three of the most important things in the life of any organism are the search for food, the urge to reproduce and the instinct of self-preservation, but all actions connected with these are an expression of the interaction between the organism and its environment, including not only the climatic and geographical conditions, but the other plants and animals among which the organism lives. In desert animals the great need is to meet the dryness of the environment and their bodies are fashioned accordingly. Animals living in polar cold must preserve the heat in their bodies. To understand these and many other things, we need to start with the simplest forms of life, the unicellular animals, for not only is each of the countless cells which compose the body of the most complicated animal essentially the same as an Amoeba, but the manifestation of life as exemplified in the behaviour of all animals is in essence the same. Indeed we can neither understand nor interpret the smallest actions of the lion or the ape until we have a fair knowledge of how these lordly animals have, through the countless ages of the earth's history, developed from a simple insignificant form.

THE SIMPLEST ANIMAL

Although we may have to confess to ignorance on the way life began, it is, nevertheless, possible to have a fairly clear idea of the way the animals inhabiting the world to-day have come into being. The evidence of the fossils accords so closely with that derived from other sources that the main conclusions regarding the history of the animal world are no longer in doubt. The persistence with which each animal, from the fertilised egg to the adult, follows an orderly sequence coinciding with the geological history of the species to which it belongs shows that during its lifetime it re-lives to a greater or lesser extent the history of its race. This is most important in the understanding of its physical characters, as well at its behaviour, habits and psychology. We must therefore begin with the study of some form which probably comes very near to the earliest form of animal life, and *Amoeba proteus* is the universally-accepted representative of the "primordial blob of protoplasm" from which animal life sprang.

A fraction of a millimetre across, Amoeba lives in the fine mud and vegetable debris at the bottom of ponds and in almost any fresh water exposed to the weather. In appearance, as in chemical composition, Amoeba resembles the white of an egg. But there the comparison ends, for Amoeba is active, able to move, feed and reproduce itself. Under the microscope it is seen as a small mass of irregular outline, semi-transparent and granular in appearance, like a blob of oil impregnated with fine sand. As we watch, the granules in the protoplasm move about, their movement correlated with changes in the shape of the body. At one point the granules stream towards the surface of the body, and simultaneously at this point the protoplasm protrudes in a finger-like process, the pseudopodium, or false-foot, a temporary organ appearing and disappearing as the needs of the animal demand, emerging from the general protoplasm of the body, and withdrawing once more into it when its task is done; an organ simple, effective and yet wonderful in its mechanism.

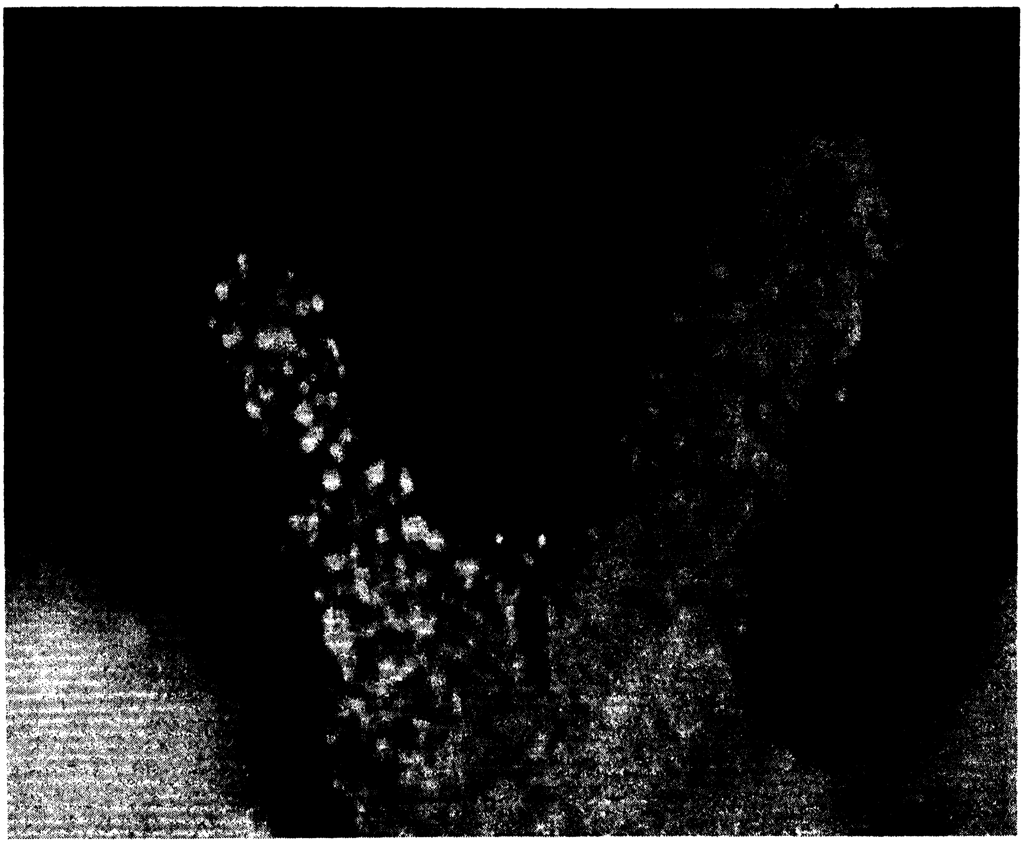
Slowly, as we watch, the pseudopodium increases in length, reaches out more and more, the movement being communicated to the rest of the body, which moves forward re-absorbing the pseudopodium as it grows. Other pseudopodia are thrown out in turn, and by the repetition of these movements the Amoeba moves slowly about on its erratic course.

Feeding is simple. As the Amoeba moves about it comes into contact with small particles of mud, vegetable debris and the like. If the particle is edible, it flows round it and engulfs it. If, on the other hand, the particle is unpalatable, the Amoeba changes course and avoids it. Clearly, there is a simple sense of taste. Respiration, the absorption of oxygen for the maintenance of life, is carried on through the whole surface of the body.

So simple is Amoeba, that drops of certain oils impregnated with sand move and behave like the real animal. To all appearances they are Amoebae, but there are two important differences: the artificial Amoebae cannot feed and therefore cannot reproduce themselves.

The differences between living and non-living matter are very small, but the ability to feed and to reproduce are the hall-marks of living matter; and in the choice of food we see one of the more vital properties of Amoeba, the possession of a power of selection, a nascent taste, which is the dim beginning of that indefinable thing, the mind.

Already we find in Amoeba characteristics or attributes remotely resembling those found in the higher animals with which we are more familiar.



Close view of pseudopodia of Amoeba showing the hyline ectoplasm and the granular endoplasm. (Magnified 2000 times.)
(Courtesy of G. B. Instructional Ltd.)

REPRODUCTION: THE CONTINUITY OF LIFE

One of the mainsprings of the existence of all animals is the urge to reproduce, to maintain the life of the race. The search for food, the care of the young, defence against enemies, protective coloration and a host of other things, physical and psychological, are intimately concerned with it. It could not be otherwise. For life to continue it must be so.

In Amoeba, the process is reduced to an easy formula; the animal merely splits into two, and two Amoebae appear where formerly one existed. This asexual reproduction is probably determined by size. There is a limit to the size to which the individual of a particular species can grow. In Amoeba, when this limit has been reached, division into two automatically takes place, so that the correct ratio between the volume of the body and the surface area is restored.

A pair of Razorbills: the male on the left is paying court to the female.

In its simplest expression reproduction is a physical response to the attainment of maximum size, as in the splitting of Amoeba into two. As we progress up the animal scale this primary motive is more and more lost sight of with the setting aside of special cells to carry out the process, until in the highest animals reproduction becomes invested with a multiplicity of subsidiary things, such as courtship, care of the young and the like.

This method of multiplication can be continued for a time, but in the end the stock becomes devitalised, and while, in some species, it has been known to continue without cease for many generations, there comes a time when a new vitality must be imparted to the stock. This is accomplished by a reversal of the process; the individuals instead of dividing into two come together in pairs, each pair fusing completely to form a single individual. Such a pairing, or fusion, is known as conjugation, and the process is called sexual reproduction, in contrast to the splitting, or asexual process, although in Amoeba, as in a large number of other animals, there is no obvious differentiation into sexes.

Amoeba is simple only by comparison with the higher animals. It is not structure-less but has very definite organs. There is a contractile vacuole, excretory in function, and a nucleus, a highly complex structure, usually situated at about the centre of the body, which exercises a strong measure of control over the behaviour of the animal. With rare exceptions, every living cell possesses a nucleus, and because of its importance deserves more than a passing notice. But first, why do we speak of the body of Amoeba as a cell? Here we have to do with one of the many misnomers explainable only by reference to history.

THE LIVING CELL

If we cut a thin slice of cork and examine it under a microscope, we find that it presents the appearance of a section of empty honeycomb; but instead of cavities bounded by walls of wax, as in the honeycomb, there are walls of cellulose. In living plants the tissues are composed of countless such units, their cavities filled with protoplasm. Since the earliest researches with the microscope were made into the structure of plants, it is easy to see how the obvious resemblance to a honeycomb caused those who saw it to speak of the units of living tissues as cells. Animal tissues present a similar appearance, except that the boundary of the cell, that is the cell-wall, is not strengthened with a

The timid fawn seeks to hide.

deposit of cellulose, but it is simply the naked surface of the protoplasm. Moreover, the structure of animals' tissues is usually less like a honeycomb; but for all that the word 'cell' has persisted and is a convenient term.

In Amoeba particularly the use of the word 'cell' in describing its body may appear anomalous, but we have to remember that all animals except the Protozoa, to which Amoeba belongs, are multicellular, their bodies are made up of a greater or lesser number of cells, usually packed like bricks in a wall. The continued use of the word to denote a unit of protoplasm is, therefore, understandable.

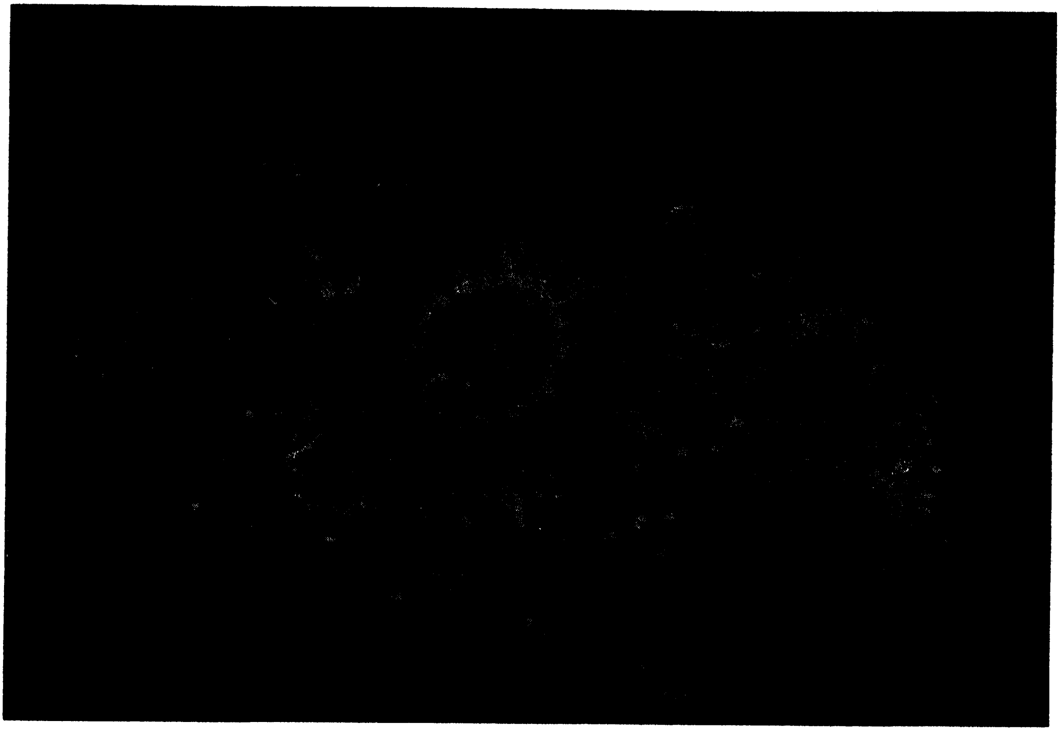
The bodies of all animals, whether the lordly lion or the timid deer, the hunter or the hunted, the carnivore or the herbivore, are built of a multitude of cells each of which is no more than a modified form of Amoeba. This kinship between all animals, from the lowest to the highest, cannot be over-emphasized.

THE SIMPLEST FORM OF ANIMAL BEHAVIOUR

What do we know about Amoeba? Through the microscope we see it moving about in an apparently purposeful manner. It moves to the right, then perhaps it gradually comes to a halt, or changes direction. Sooner or later it meets a particle of matter. If edible it will eat it; if not it will reject it, or pass it by. If we could watch long enough we should see that Amoeba grows in size; that later it may withdraw its pseudopodia and rest. We may even see it divide into two; that is to say, we shall see it reproduce. We may even see two Amoebae 'marry' or 'mate', or as we say for such simple animals 'conjugate' though it has not been observed yet.

In describing such behaviour it is easy to fall into using words and terms used to describe the behaviour of more highly-evolved animals. They suggest purpose, however slight, even an intelligence, however dim. It must be recalled, therefore, that the protoplasm of Amoeba is automatically responding to external changes, that this is the fundamental characteristic of

Reproduction may take many forms in the Animal Kingdom; not always does it involve sex, but a sexual interchange is sooner or later necessary to revitalise the stock, and where life has reached its highest expression there is the distinction between male and female.

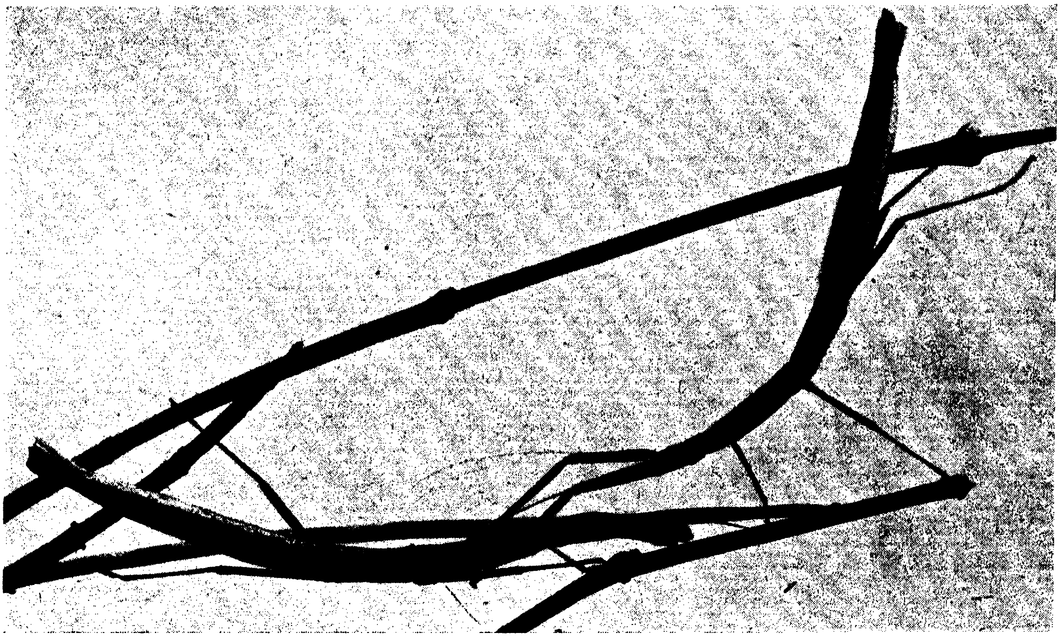


The Sea-anemone *(Tealia felina)*, in common with the lower forms of animal life, such as sponges, Coelenterates and most worms, is hermaphrodite. There is no male or female sex, but each individual bears both eggs and sperms. *(Photo by Douglas P. Wilson.)*

Snails are also hermaphrodite, but in conjugation are mutually fertilising.

living matter, without which life would be impossible.

Amoeba has no sense-organs, no eyes, ears, nose or tongue, for it has no nerves or brain, yet it will not eat anything that is inedible and will move away from those things, such as grains of sand, which are useless to it. However, it will shrink from a touch, move away if the temperature of the water is too high or too low to be favourable to it. It will react to an electric current, or to a vibration. It will move away from intensely bright light, or from chemical substances likely to injure it. How can a living organism do this if it has no sense-organs, no brain and no nerves; it is little better to all appearances than a drop of oil impregnated with fine grains of sand? The answer is that the behaviour of Amoeba is governed by tropisms. This is a convenient way of saying that it reacts in a definite manner to external stimuli. In other words there is an innate physico-chemical response within the protoplasm to such things as heat or cold, bright light or darkness, and other natural phenomena, and the response may be negative or positive. In this simple organism, therefore, the manifestation of life is the expression of the organism's reactions to its environment – in a purely mechanical way. As animals become more advanced their behaviour is governed not only by tropisms but, in addition, by reflex actions, instinctive actions and finally thought itself.



In Stick Insects, as in Plant-lice, Saw-flies, many small Crustacea and other Invertebrates, the normal reproduction is bv parthenogenesis. That is, the egg develops without being fertilised and the individuals are all females. Sooner or later, however, males appear and fertilisation takes place.

THE PRIMARY MECHANISM OF ORGANIC EVOLUTION

The concept of organic evolution may be, perhaps, expressed as a primary urge not to remain static. We have seen that the essential nature of living protoplasm is change, expressed in the continual dying away and renewal of the fabric combined with the continuous adjustment to the environment. This impulse to keep on the move is inherent in all living organisms. What then are the factors determining its course? The first and principal is the factor of heredity, the transmission of parental characters to the offspring, the fact that like begets like. In this the general pattern tends to be maintained;

but it is common knowledge that no child resembles exactly its parents, or either one of the parents. No matter how much a son may resemble his father, or a daughter her mother there are always points of difference. Even in Amoeba where reproduction is a simple process of splitting of the protoplasm and nucleus (amitosis), the two individuals resulting from the splitting differ slightly in size. Furthermore, once independent they are subjected as a matter of course to differing environmental conditions. Even more so are the offspring of higher animals. Thus, while the force of heredity tends to the maintenance of a pattern, that pattern is not uniformly maintained. If this were not so, and if in addition the environment were uniform and constant, a state of equilibrium would have been maintained from the beginning of time, and evolution could not have taken place.

While the factor of heredity determines the pattern the tendency to vary ensures continual upsetting of the pattern. Some of the variations will be of advantage to the individuals possessing them, giving them the better chance of survival. So we may accept the general principle of the survival of the fittest as enunciated by Darwin.

The reverse is referred to as the elimination of the unfit, and both this and the survival of the fittest may depend upon such things as temperature, light, humidity and other physical conditions as well as the abundance or scarcity of food or enemies.

In the higher animals sex is strongly marked. Nobody, for example, can fail to tell a lion from a liones.

For convenience sake, the normal variations are classified as meristic, where a change in numbers is involved, and fluctuating, where variations in size and shape occur. There are other forms of variation to be noted, such as atavism, or the recurrence in a descendant of the characters of a remote ancestor, which have remained dormant, and hybridism, the production of offspring by parents belonging to two different species. In

PLANTS OR ANIMALS?

It is not possible to give an exact definition of a plant or an animal, but the broad differences are illustrated here.

A. The normal plant cannot move from place to place, has no sensitivity and manufactures its own food.

B. Occasionally a plant is sensitive and captures food, in addition to that which it manufactures in its leaves, as in the Sundew, here seen capturing a fly.

D. A young deer, typifying the animal. Its senses are alert, it starts at every sound, sight and smell. It feeds on vegetation. The actions of all animals, even of those we call higher animals, are determined by influences which have developed over a long period of time. The deer startled at a flash is reacting in a manner comparable with that of the unicellular animal moving away from light. It is only a question of degree.

C. A seemingly plant-like sponge from tropical seas; it cannot move about once it is adult, has no sensitivity, but cannot manufacture its own food.

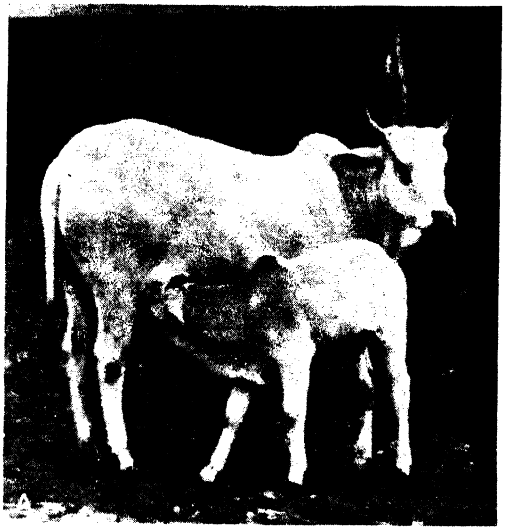
addition there is the vast field of teratology, or the study of monstrosities, serious malformations and marked deviations from the normal, which in time may cast considerable light on the normal processes.

WHAT IS AN ANIMAL?

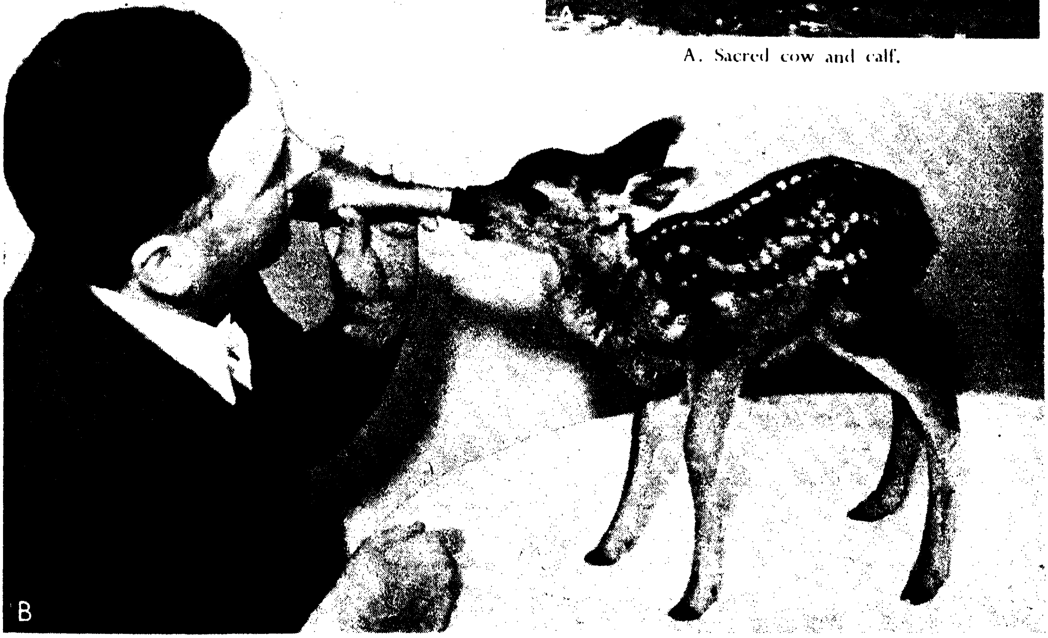
How do we know Amoeba is animal? To answer this question satisfactorily it is necessary not only to define what we mean by an animal, but also to deal with the etymology of the word itself. A good dictionary definition is "Any member of the group of living beings typically endowed with sensation and voluntary motion, as distinguished from a plant". Unfortunately for our present purpose there is an historical hindrance; that in common usage there is a tendency to reserve the use of the word for the larger, four-footed beasts such as dogs, horses, lions, elephants and so on, which zoologically speaking are mammals. So people speak of animals and birds, and reptiles, fishes, insects, worms, whereas all these and many more are, in a zoological sense, animals, and the grouping must include a very large number of living things, often of microscopic size, which ordinarily do not come within our common experience. This must be clearly appreciated or much of what follows will be unintelligible.

To return to the dictionary definition, an animal is "endowed with sensation and voluntary motion". A sponge is an animal, but very few

One of the main differences between plants and animals is that plants can, with few exceptions, manufacture their own food, and animals must have it prepared for them.



A. Sacred cow and calf.



B. Young deer being artificially fed.

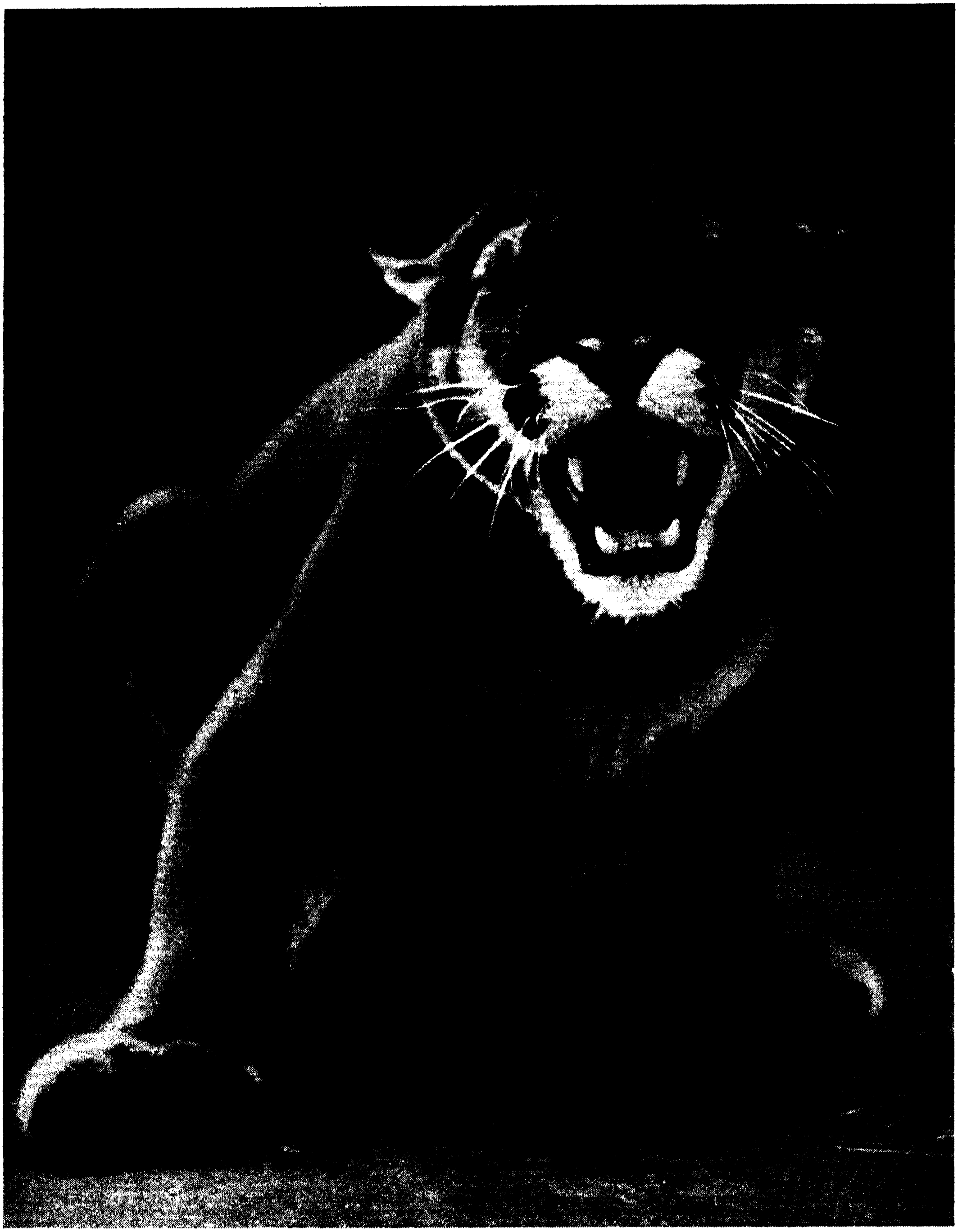
sponges have any obvious ability to perceive sensation, and all, once they reach the adult stage, are fixed and without the power of voluntary motion, although they can and do move in both the larval and young stages. Add to this that our usual acquaintance with a sponge is in the bathroom, where we use its skeleton for washing, a skeleton looking decidedly like some form of plant growth and it is easy enough to see why most people look upon a sponge as a plant. But it is an animal.

Corals and sea-anemones have a plant-like appearance, but both have the power of reacting to sensation, and sea-anemones, in spite of appearance to the contrary, have very strong and diverse methods of voluntary motion. To draw an exact distinction between plant and animal we must postulate something in addition to "sensation and voluntary motion", particularly as some plants, for example Mimosa, are sensitive to the touch and respond by folding their leaves back, and some unicellular plants have the power of voluntary motion equal to or even exceeding that of some animals.

The first exact criterion is that plant cells have walls of cellulose, and those of animals are said to be naked. In a piece of wood or cork it is the stout cellulose walls, persisting after the living tissue is gone, that gives us what we call wood or cork, but the presence of cellulose can be adequately detected only by microscopical examination or by chemical test, although a rough guide is obtained by burning, when animal tissue gives off a characteristic "animal smell" very akin to that of burning hair. The next, obvious, criterion is that plants are green, owing to the presence of chlorophyll, and animals are not ordinarily green. But fungi, which are plants, are not green, while many animals are. Here we have, however, a good clue. The green chlorophyll enables a plant to manufacture its own food, and only in such plant-animals as *Euglena* is an animal able to do this. We can, therefore, define an animal as a living organism which eats solid food, and normally has the power of voluntary motion and is capable of perceiving sensation. Amoeba, as we have seen, is an animal within these limits.

TABLE TO SHOW THE NUMBER OF EGGS LAID EACH YEAR BY A FEW TYPICAL MARINE ANIMALS

Group	Name of animal	Number of eggs laid each year by one individual
Worms	*Sphaerosyllis tetralix*	64
	Polydora ciliata	100—450
	Chaetopterus variopedatus	10,000
	Cerebratulus lacteus	100,000,000
Starfish	*Henricia sanguinolenta*	38
	Asterias mülleri	50—110
	Asterias rubens	2,500,000
	Luidia ciliaris	200,000,000
Molluscs	*Littorina littorea* (periwinkle)	10,000
	Ostrea edulis (European oyster)	1,000,000
	Mytilus edulis (mussel)	25,000,000
	Ostrea virginicus (American oyster)	500,000,000
Crabs, Lobsters, Shrimps	*Palaeomonetes varians*	100—450
	Nephrops norvegicus	1,000—5,000
	Crangon crangon	10,000—35,000
	Homarus vulgaris	12,000—15,000
	Carcinus maenas	185,000
	Carcinus pagurus	3,000,000
Fishes	Herring *(Clupea)*	50,000
	Sole *(Solea)*	570,000
	Flounder *(Flesus)*	1,000,000
	Cod *(Gadus)*	6,000,000
	Turbot *(Rhombus)*	9,000,000
	Ling *(Molva)*	28,000,000



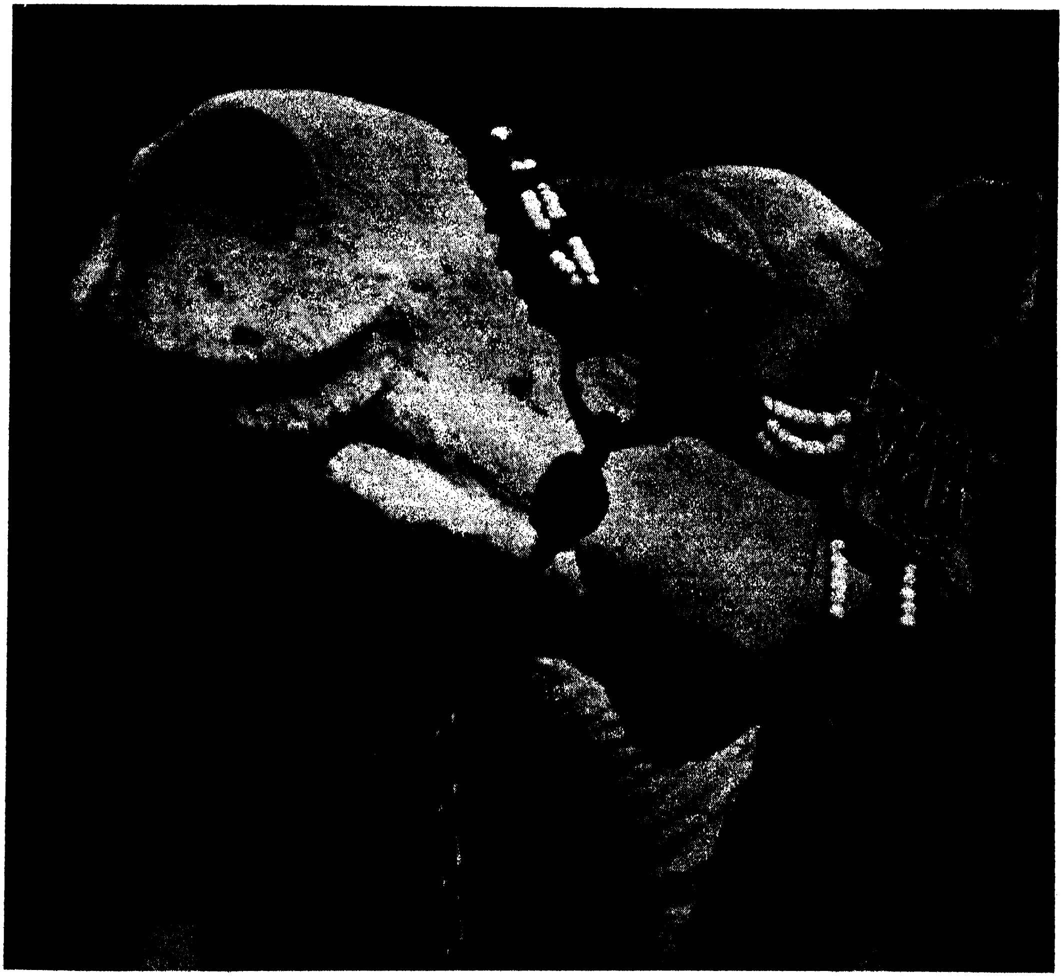
The Cougar or Puma, of America, a large unspotted cat standing two feet high at the shoulder, in an attitude of ferocity. We are prone to make too great adifference between the wild beasts and human beings, but unless it is realised that there is a kinship between all animals, and between them and ourselves, many aspects of human behaviour will remain unexplained.

CHAPTER II

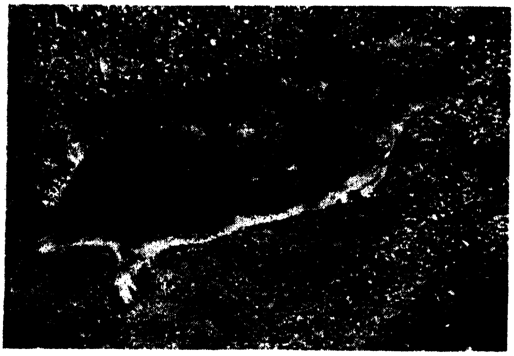
THE MECHANISM OF LIFE

LIVING AND GROWING

WE have already seen that the body of an Amoeba is less simple than is commonly supposed, and it is clear from the most casual observation that the body of one of the more familiar animals, say a dog or horse, is an extremely complicated thing. Yet however much one organism may differ from another there are certain things they have to do, certain actions or functions to perform, that life may be maintained.



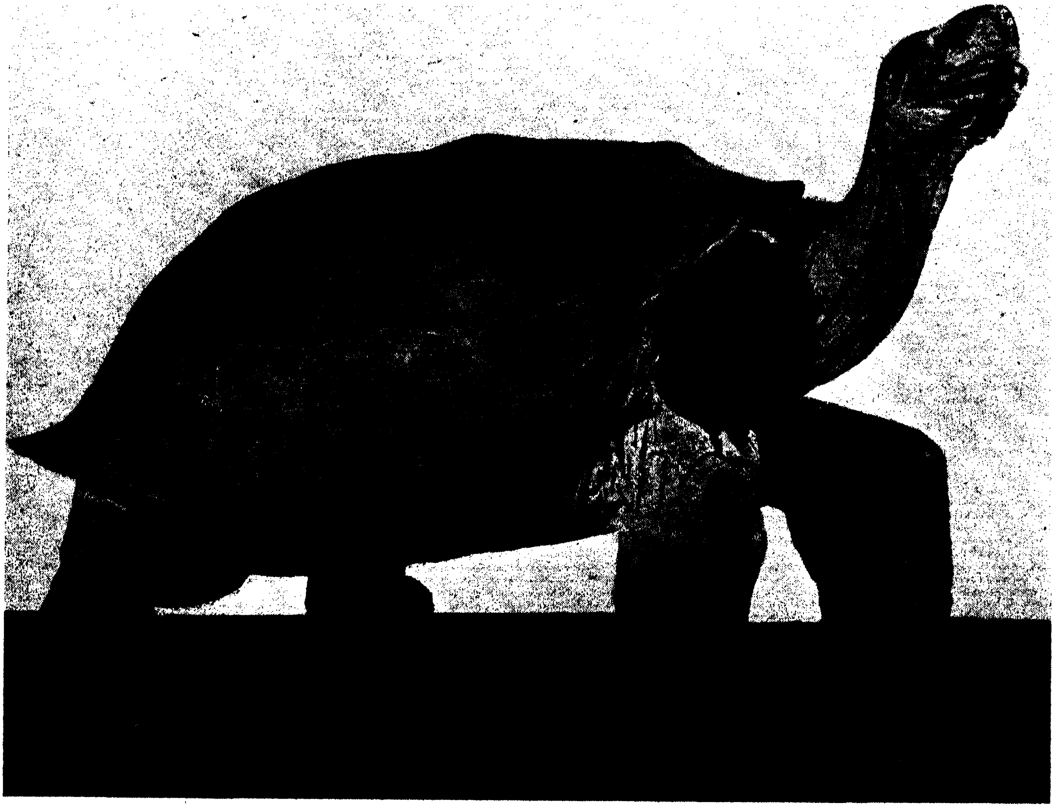
The camel has a coat of thick hair to protect it from the heat of the desert, in the same way as the polar bear is protected from the Arctic cold. The camel is not found wild to-day. Here is a Cairo camel with a licence plate on its bridle. It is used for hauling cars and trucks.



The mole is probably the most restless and active of animals, seeming never to rest, always seeking out food, energetically and nervously, but if deprived of food for a few hours it dies. The constant output of energy must be counterbalanced by a continual intake of food.

To begin with, an organism must safeguard itself against the destructive forces of the environment. It must protect itself from heat and cold, from mechanical friction and impact. It must choose a place to live and must avoid attack from other organisms. Every simple action, no matter how small, connected with these involves an expenditure of energy. So the first thing needed for the maintenance of life is the expenditure of energy. Just as the steam-engine consumes fuel so must the living organism. The difference is that in the living organism the fuel is to a large extent the substance of which the body is composed.

Combustion is simply another name for oxidation. When charcoal is burnt in air it enters into combination with the oxygen of the atmosphere to form carbon dioxide and energy is set free in the form of heat and light. Once united



The lethargic tortoise can fast for long periods without harm and correspondingly it uses the minimum of energy in its daily activities.

A stud Merino flock.
There is no remarkable difference in the size of individual adult sheep, or in any group of vertebrate animals. Compare this with the range of size in certain aquatic invertebrates (see figures on p. 44).

in this way two elements cannot be separated except by the expenditure of energy, and when they unite a corresponding amount of energy is liberated. So long as carbon and oxygen remain separate the energy remains latent, and is called potential energy. The proteids contained in protoplasm are unstable compounds containing a large amount of potential energy, and it is the breaking up of such substances that releases the energy required for the processes of living.

Nutrition is concerned with the building up of the body, making good the waste caused by the expenditure of energy, thus providing fresh fuel for a further supply of energy. There is, however, yet another difference between the steam engine and the living organism. In the former the fuel is consumed, energy is expended and the waste, the ash, removed. In the living organism the fuel (i.e. the food) not used in the production of energy may result in the formation of new protoplasm. In other words, the organism may increase in size, that is grow.

The building up of protoplasm and its breaking down for the release of energy are known collectively as metabolism, and to achieve it there are required, in addition to a supply of food, the processes of respiration (or oxidation) and excretion (the clearing away of waste products). We have in these the three primary requirements of any living organism.

THE IMPORTANCE OF REPRODUCTION

Metabolism is the combined process of building up and breaking down of protoplasm, but the two components do not need to balance. If the building up proceeds more vigorously and rapidly than the breaking down, if food is abundant and the expenditure of energy comparatively low, then growth takes place. In all organisms there is a limit to the size they may attain, and in a simple organism like Amoeba as this size is approached the body begins to break into two. In other words, the animal reproduces itself, and the life of an organism is seen as an incessant getting and expending, resulting in the expenditure of energy as heat (in warm-blooded animals), light (in glow-worms, fire-flies, etc.) and movement, with at intervals reproduction. Every living thing exists primarily for its own benefit, but it also exists for the benefit of future generations. Consequently, although the acquistion of food, the escape from enemies and the search for bodily comfort may determine a large proportion of its behaviour, the urge to reproduce also plays a dominant part and cannot be denied.

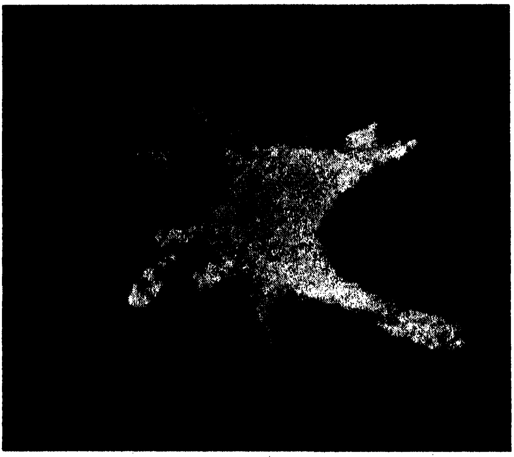
Both growth and reproduction are important factors in the evolution of animals, and their relation to it must be more fully considered.

UNICELLULAR AND MULTICELLULAR ANIMALS

If there were no animals in the world except human beings and Amoebae we should still be forced to the conclusion that there was some relationship between the two, or at the very least a marked similarity. On the one hand we have the fact that Amoeba can maintain life successfully and that to do so it is called upon to perform all the functions of the human being but in very much simplified terms. On the other hand we have the fact that our bodies are made up of millions upon millions of cells each one of which is fundamentally similar to Amoeba. Modifications have, of course, occurred and the shapes and sizes of our cells differ according to their position in the body. A cell from the liver is recognisably different from a brain cell. Nevertheless, it is as though a countless

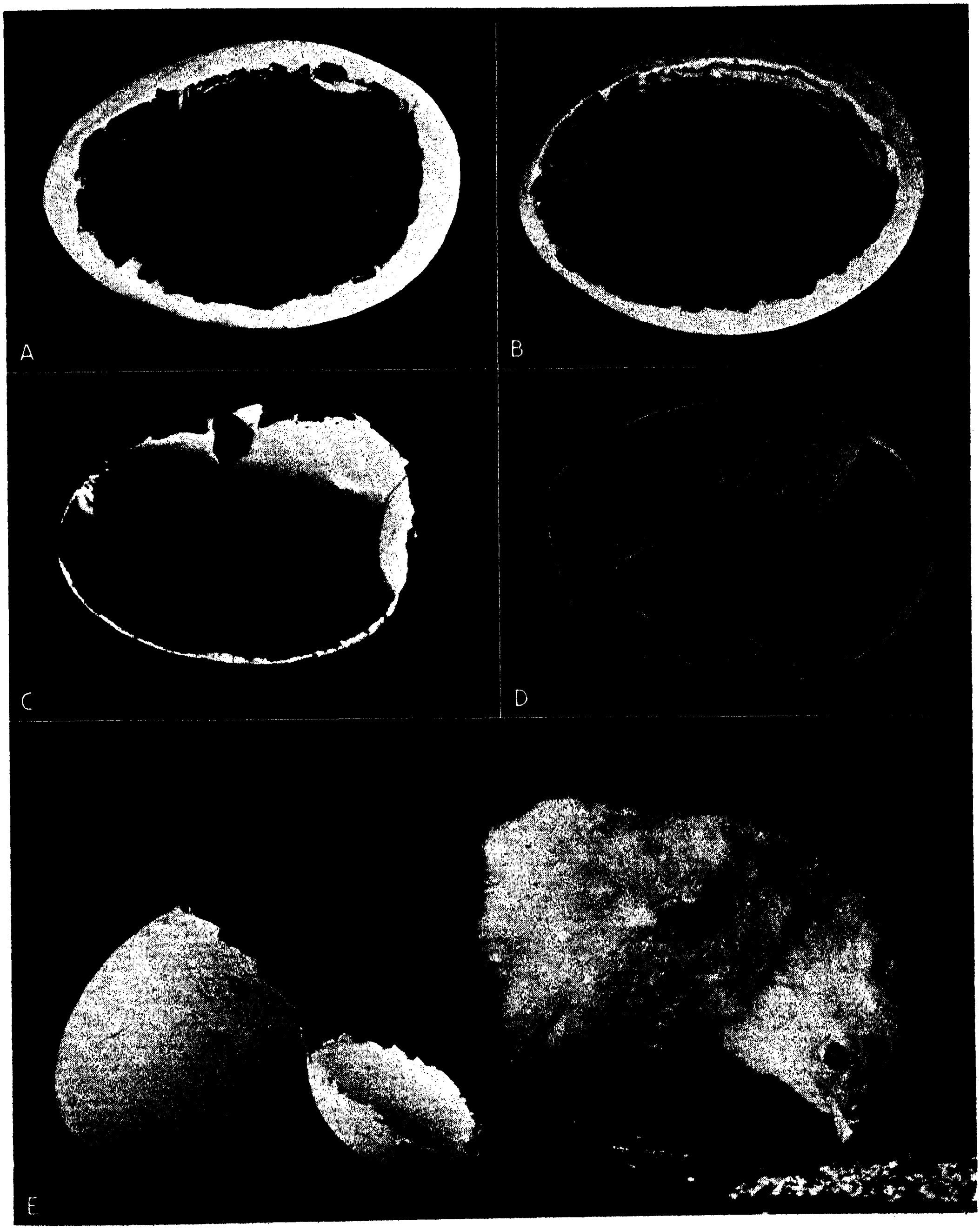
Two specimens of the Purse-sponge, *Grantia compressa*, a species found abundantly between tide-marks on the shores of Europe. The usual size, as shown by the specimens on the left, is from 10–20 mm. high. The specimen on the right is 60 mm. high.

Among highly-organised and terrestrial animals the variation in size of individuals of a given species is not very great. In the more primitive and aquatic species the range of size is markedly greater. An unusually large *Grantia* growing in water heavily polluted with decaying organic matter, 180 mm. high.



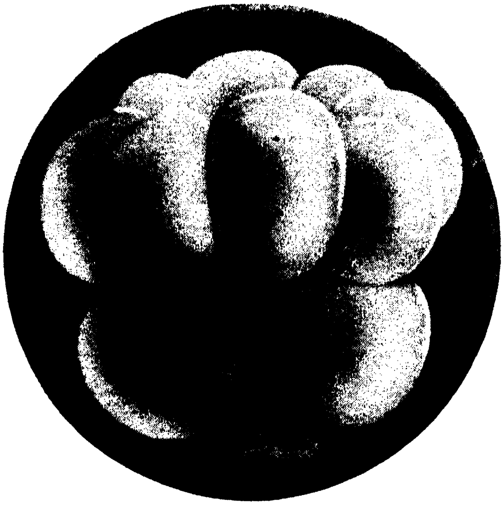
Although the ova or egg-cells are usually rounded, those of many species, especially among the more primitive Invertebrates, are amoeboid. The *Amoeba* shown here could equally be the ovum of several widely separated species of Invertebrates. In this is seen suggestive evidence of a unicellular ancestry for all animals. (Magnified 100 times.)
(Courtesy of G. B. Instructional Ltd.)

Although of such large size, the egg of a domestic fowl is still no more than a single cell, like that of any other animal, but is heavily charged with yolk and contained in a limey shell.



(A) A hen's egg broken open to show the inner yolk with, towards the top and showing up darkly, the germinal disc from which the chick embryo develops. (B) On the 7th day of incubation the embryo, hardly seen but already developing, is throwing out a network of bloodvessels through which the yolk can be absorbed for food. (C) Shell emptied on the 11th day of incubation to show the well-expanded air-space at its broad end. It is from the air-space that the young chick gets its first gulp of air before breaking open the shell. (D) The young chick, after 20 days' incubation, ready to break its way out of the shell. (E) A young chick of the domestic fowl is able to feed itself as soon as it is hatched.

number of Amoebae had decided to co-operate in building a large community, had decided that certain cells should concern themselves with nutrition, others with respiration, others with reproduction and so on. If any doubt be still felt it is possible to point to the leucocytes, or white blood corpuscles, and say: here is one cell at least from the human body which if found wandering on its own would be accepted without hesitation as a species of Amoeba.



Whether the ovum is amoeboid or rounded, the first stage in the development of the fertilised egg (that is, when it begins to divide) finds the segmenting parts assuming a rounded form. Here is shown a developing embryo of a Sea-urchin. After four cleavages the 16-cell stage has been reached. There is a strong suggestion here that the Metazoa, or multicellular animals, have arisen from the unicellular by dividing cells failing to separate. (Magnified 100 times.) *(Courtesy of G. B. Instructional Ltd.)*

When we come to examine the Animal Kingdom as a whole we find that not only are all animals equally composed of aggregates of cells fundamentally the same as the Amoeba but there is an obvious increasing complexity as we pass from one to the other. We can with confidence then accept the view that the multicellular animal is related to the unicellular animal and that, moreover, it has been derived from an original unicellular animal. This fits in with the findings of the palaeontologist and also with the fact that we (i.e. all animals, including human beings) all start life as a single cell, the ovum. The main difficulty presents itself when we seek to bridge the gulf between the two. The Protozoa, as the unicellular animals are known collectively, are for the most part soft-bodied, with the result that there is no fossil record of them except where they possessed a hard skeleton, as in the Foraminifera and Radiolaria. Any transitions from the unicellular to the multicellular have not been preserved. Also, there are comparatively few examples living to-day to help fill in the picture. It is, however, possible to obtain some slight direct evidence. Certain minute plants, for example, known as *Pandorina* consist of a group of 16 to 64 cells, each differing little from *Euglena* (see p. 138), enclosed in a gelatinous envelope. It is as though *Euglena* had started to divide and the resulting individuals instead of separating had remained together. *Eudorina* is a similar plant, but here the individuals are combined to form a hollow sphere, and the process is taken even further in the beautiful *Volvox*. Among animals, some of the Radiolaria (Protozoa), such as *Sphaerozoum*, form similar colonies, but there is not the same series of steps to be found in the Animal Kingdom as we find among plants.

It is not difficult to imagine that with the further development of this colony formation a differentiation could ensue resulting in a division of labour, some cells becoming nutritive, some reproductive and so on.

Support is given to this by the behaviour of sponges. These animals consist of cells having different shapes, sizes and functions, but it is possible to pass the tissues of a sponge through fine silk and to separate the cells, whereupon each cell will lose its characteristic form and become in effect an Amoeba, showing the same irregular, changing shape. There is an important difference, however, in that the sponge cells will not live independently for long. Instead they wander about until they meet their fellows, when they join up with them in larger and larger groups until a new sponge is formed.

THE MULTIPLICATION OF CELLS

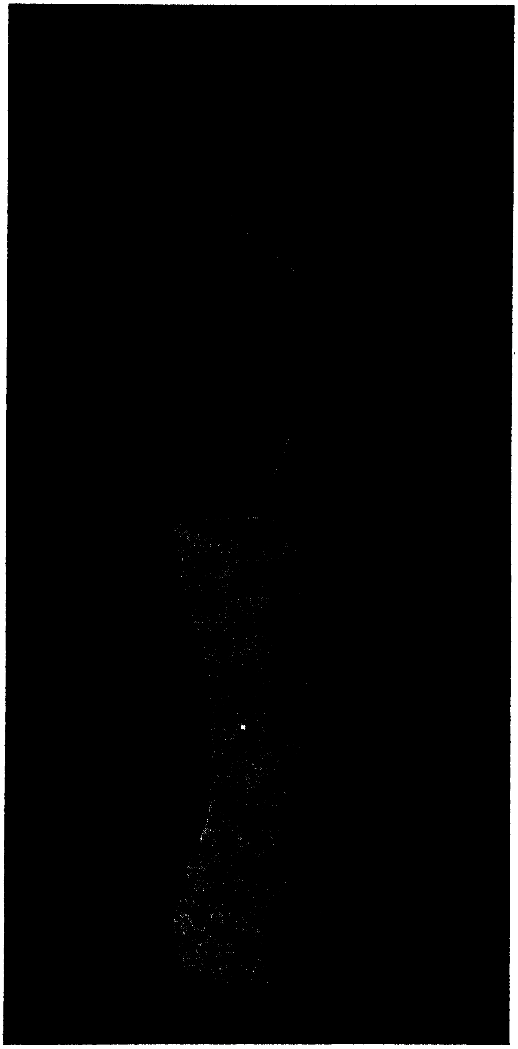
Reference has been made in Chapter 1 to the factor of heredity which determines the pattern to which animals conform, and it now remains to elaborate this point. The division of cells is not so simple as the splitting of Amoeba might suggest. Each cell consists of a cytoplasm and a nucleus and before division can take place a very complicated series of events must be set in train. The granules in the nucleus come together to form a long coiled thread which ultimately breaks up into a number of chromosomes. These split longitudinally and one from each pair so formed passes to each pole of the nucleus, after which the cell divides, each half of it receiving its portion of the chromosomes. It is not difficult to imagine the complex series of physical and chemical processes which must take place for so orderly and controlled an event to take place.

This mitosis, as it is called, has another significance. The characters of the body are controlled by heredity factors (or genes) located in the chromosomes. It is not our purpose to deal here in detail with the science of genetics, nor to say more about the forces of heredity. There is however, a tremendous implication in the knowledge that the course of our lives, the structure of our bodies and those of all animals are controlled by forces enclosed in and operating from the contents of the central part of a cell, itself a minute fraction of a millimetre across. And it must be appreciated that even so comparatively unimportant things as whether a man shall be tall or short, fair or dark-haired, and many other things besides are determined by portions of the protoplasmic content of the nucleus of a cell which even the most modern scientific technique is unable to locate or isolate.

To pursue the story further, we may say that these hereditary factors are responsible for the unfolding pattern of life, for without them an orderly sequence would be impossible. It is clear then that not only the structure of animals but their behaviour depends to a large extent on the ultra-microscopic composition of the nuclei of their cells.

THE ORIGIN AND EVOLUTION OF SEX

It has already been remarked that three of the most important instincts of living organisms are the search for food, the urge to reproduce and the need for self-preservation. The urge to reproduce is not so constantly a motive underlying behaviour but at the right season it releases a flood of energy to which everything else is subordinated. One writer tells of a group of Eland bulls quietly grazing, contented, amicable, docile. Suddenly they got the scent of a group of cows a distance away. Immediately their



One of the earliest steps in the evolution of multicellular animals was taken when different cells began to assume different functions and shapes. Thus occurred what is known as a division of labour. In sponges, the earliest Metazoa, the body consists almost entirely of cells closely resembling Amoeba, but one group, the collar-cells, which are responsible for driving water through the body, have assumed a specialised form. (Magnified 2000 times.)

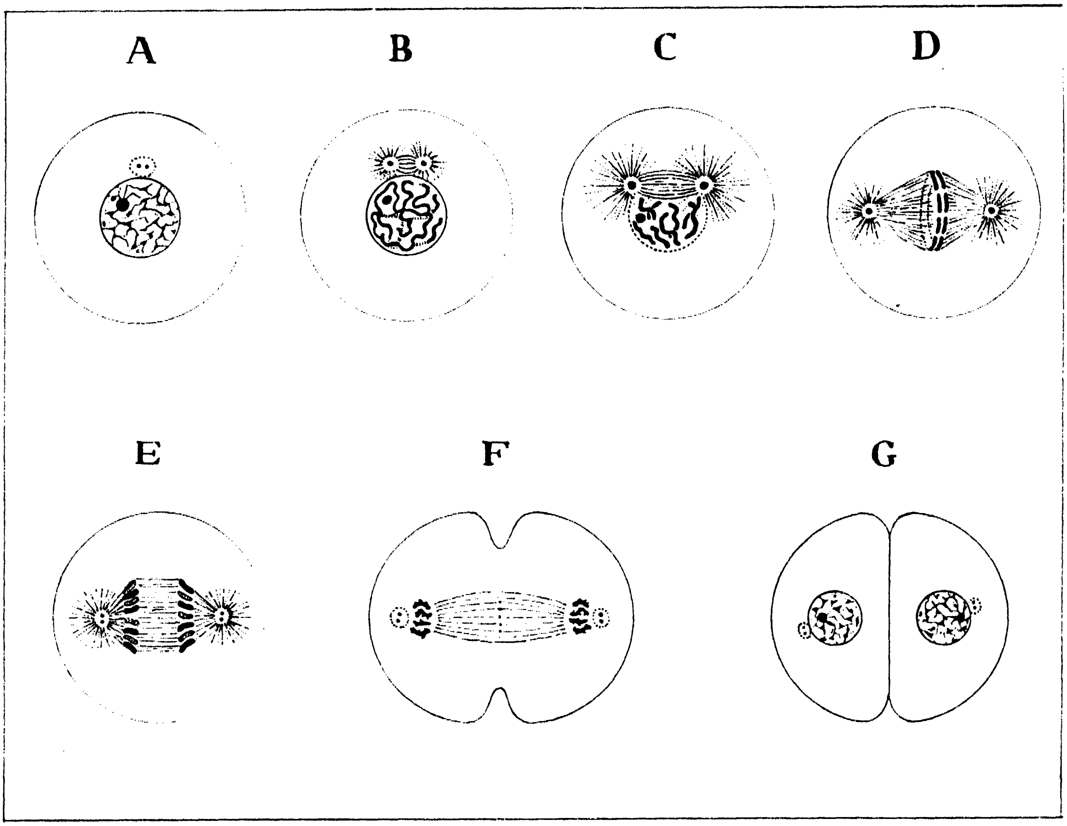


Diagram showing the changes that take place in the nucleus of a dividing cell.
A. A cell with its nucleus; above the nucleus two centrospheres have appeared. B. The chromatin of the nucleus becomes resolved into a long thread or spireme, as the centrospheres move away from each other. C. The spireme breaks up into chromosomes. D. The centrospheres have reached opposite poles in the cell and the protoplasmic fibres connecting them form a spindle on which the chromosomes arrange themselves, after having split longitudinally. E. The half of each chromosome begins to move towards its centrosphere. F. The daughter chromosomes (the halves resulting from the splitting) beginning to form fresh nuclei as the cell wall begins to grow in. G. The division of the cell is complete.

whole character changed. It was as though a roaring tornado had been let loose. Perhaps the picture is a little overdrawn but that merely serves to emphasize the point. There can be little doubt that the urge to reproduce is as tremendous as this.

Since we are now dealing with so important and compelling an aspect of animal behaviour it will be as well to trace its origin and mechanism. As we have seen, in Amoeba reproduction is a comparatively simple thing and intimately linked with feeding and growth. In the Metazoa, or multicellular animals, however, the same increasing complexity is seen as in other things. In the sponges there are no special sex-organs. At the breeding season certain body cells take on the function of ova and others of spermatozoa. Moreover, there are no male or female sponges; all are hermaphrodite, producing both eggs and sperms. In the Coelenterates special reproductive organs, known as gonads, are beginning to appear, but there is still no differentiation into separate sexes. As we go up the animal scale, the reproductive organs become increasing complex and there is a marked distinction between the individuals that bear the ova and those that bear the sperms. In other words, not only are the individuals of the species differentiated into male and female, but the distinction between the two sexes is

A robin chick at the moment of hatching.

becoming increasingly marked. The increasing complexity of the reproductive organs and the greater differences between the male and female are not unrelated. They are due to secretions from the gonads resulting in the formation of secondary sexual characters. Before dealing with these, however, we should see how the sex of the individual is determined.

A number of views have been put forward to account for the determination of sex, but modern Genetics has shown that the control of sex, whether an individual shall be male or female, rests not in such things as nutrition, or other environmental factors, but in the chromosomes.

SECONDARY SEXUAL CHARACTERS

Connected with the sexual differentiation, more especially in the higher animals, are numerous secondary sexual characters which do not appear necessarily to be connected with the reproductive organs. Some familiar examples are the antlers of deer, outgrowths of hair on the male, as in the lion's mane, the colours of many cock birds, and so on. It is generally assumed that these appeal to the aesthetic sense and so contribute toward the mutual attraction between male and female. Other secondary characters of this nature are the spurs worn by certain cock birds, which are used in combat for possession of the female. Finally, it is noticeable that in birds it is the cock that sings, so that song also may be regarded as a secondary sexual character.

Many investigations have been made into such matters and it is becoming abundantly clear that these ornaments or attributes are directly connected with secretions from the gonads. For

In deer, antlers are worn only by the stags, except in one species, the reindeer or caribou. Antlers are therefore to be regarded as a secondary sexual character. But even where both sexes are antlered, there is a markedly belligerent disposition in the male. Secondary sexual characters may include, therefore, both physical and emotional characters.

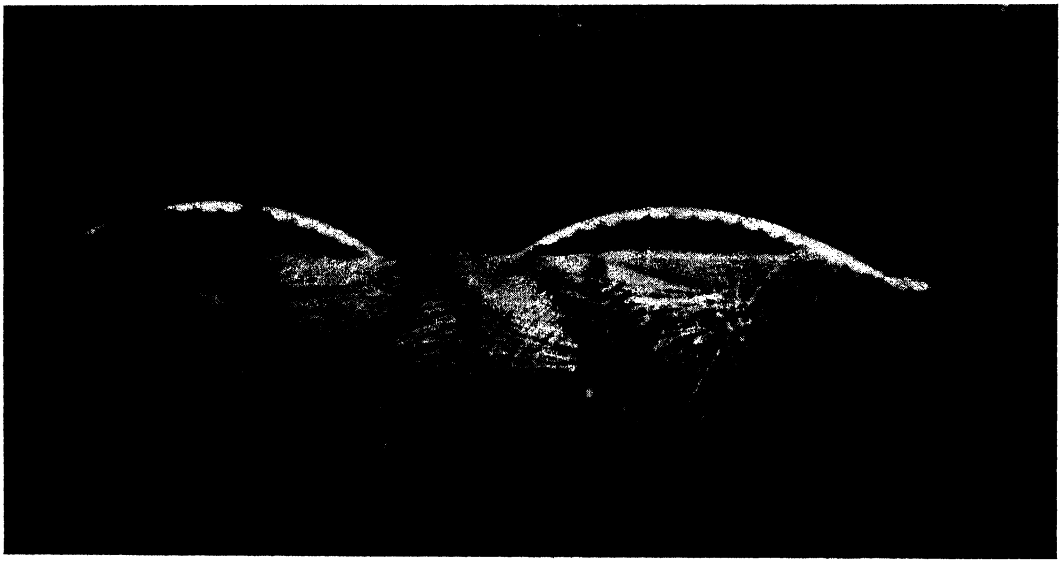
The male lyre-bird, tail folded, singing from a stump. Bird-song is the prerogative of the male and must again be regarded as a secondary sexual character.

example, a young deer castrated will not develop antlers, and a deer with antlers will lose them prematurely if castrated. The song of birds, also, has been shown to depend upon the growth of the gonads, or of certain phases of their growth, and this in turn is dependent upon the duration and intensity of the daylight, so that birds which normally sing for a part of the year can be made to continue singing long after the season is past by keeping them under suitable illumination.

REPRODUCTION WITHOUT SEX

Although as a rule the ovum, or egg, does not develop unless fertilised, there are instances known of the development of unfertilised eggs, the process being known as parthenogenesis. So, although so much insistence is laid on sexual reproduction it does not follow that the process is entirely essential for the production of offspring. Nevertheless, even in the most pronounced cases of parthenogenesis the time must come sooner or later when the sexual interchange is necessary to revitalise the stock. Perhaps this only serves to emphasize the value of the sexual process as a vital stimulant in the sequence of life.

There are in addition other non-sexual or asexual methods, such as budding and fragmentation, but these occur mainly among the lower Invertebrates, although there are instances known from the lower Vertebrates. One of the best-

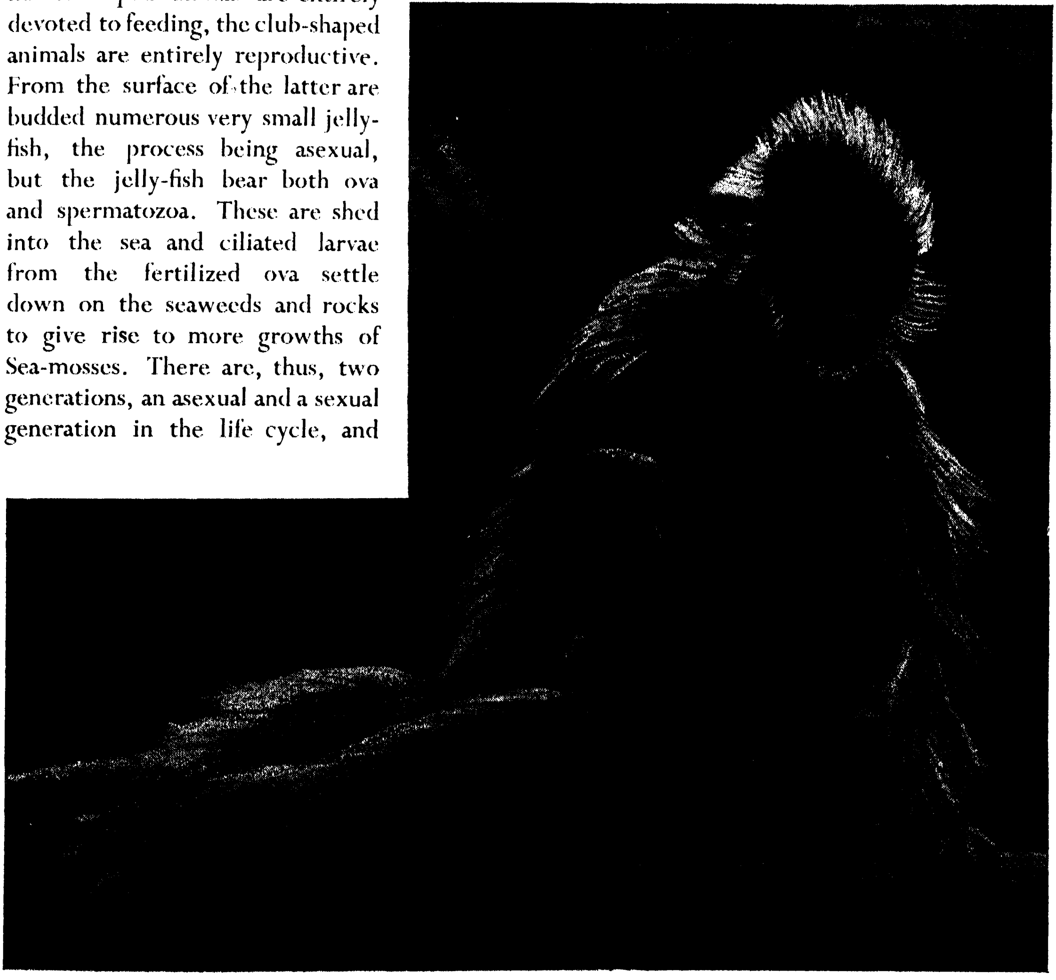


The male lyre-bird of Australia has a magnificent tail which he displays proudly to the hen, she having nothing so fine. Since this elaborate set of tail feathers is associated only with the male it represents a secondary sexual character.

known cases of budding is found in the Hydroids or Sea-mosses. These are delicate growths found on seaweeds and rocks. Each upright stem consists of a number of flower-like animals formed as a result of budding, the buds instead of separating have remained attached to the parent stock, the whole being enclosed in a common horny tube. Each member of the colony is seated within a horny cup. At intervals up the stem appear vase-shaped outgrowths from the horny sheath enclosing a club-shaped animal continuous with and produced from the common stem of the colony. The two different kinds of animals produced in such a colony have entirely different functions: the flower-shaped animals are entirely devoted to feeding, the club-shaped animals are entirely reproductive. From the surface of the latter are budded numerous very small jelly-fish, the process being asexual, but the jelly-fish bear both ova and spermatozoa. These are shed into the sea and ciliated larvae from the fertilized ova settle down on the seaweeds and rocks to give rise to more growths of Sea-mosses. There are, thus, two generations, an asexual and a sexual generation in the life cycle, and the phenomenon is known as the Alternation of Generations.

OFFSPRING WHICH DO NOT RESEMBLE THEIR PARENTS

Considerable point has been made in a previous chapter of the important bearing upon the Theory of Evolution made by a study of the life-histories of animals. It was pointed out that all animals in their development recapitulate the history of the race; but whatever may be the changes taking place during their development, it is usually the case that at the moment they are



Another secondary character closely linked with sex is the development of the mammary glands, functional and well-developed in the female only.

Many examples will be referred to in subsequent chapters of offspring that differ markedly from the parents, but the best-known is that of insects. The Pine Saw-fly *(Lophyrus)* caterpillar, on the right, might almost be a different animal to the perfect insect shown at the top left of this picture. The cocoons containing the pupae are shown below the fully-grown Saw-fly.

born or hatched the young animals do not differ materially from the parents. This last is an idea to which we have become accustomed and is reflected in the phrase, like begets like. There are, however, many cases where this is not true, although ultimately, of course, the balance is restored and the offspring which have differed so markedly from their parents do eventually either grow to resemble them or give rise to a further generation which does. Again we see a manifestation of the remarkable control exercised on the course of life by the contents of the nucleus of the cell.

An alternation of generations is seen in several groups of animals besides the Hydroids, in the Trematode worms, for example. Other offspring differing from the parents are found in those groups where the larval life is passed in a free-swimming existence and the adult is sedentary or nearly so, as in Echinoderms and Mollusca; or in the Arthropods where a partial or complete metamorphosis takes place, as in the familiar life-history of the butterfly.

THE THEORY OF EVOLUTION

The Theory of Evolution is the only workable hypothesis by which it is possible to give a reasonable interpretation of all the observed facts of structure, adaptation, distribution and habits of plants and animals. The only thing

It is seldom that the young animal precisely resembles the parents. Usually the differences are mainly concerned with size and colour, as in the two Cape Penguins shown here.

upon which biologists are not agreed is the method. The various views put forward may be briefly summarised as follows:

Lamarck, the French naturalist (1744–1829) was the founder of the theory of evolution in the modern sense, as opposed to the separate creation of species. He held that changes in the environment, and in function or habits, lead to changes in structure, and that such changes were transmitted from parent to offspring. Lamarckism, the name by which this idea is known, was for long ignored, but in more recent times has received increasing support. To-day, in a modified form, it is known as Neo-Lamarckism.

Darwin, the English naturalist (1809–1882) noted that all organisms tend to produce offspring varying slightly from their parents and suggested that a process of natural selection favoured the survival of those individuals whose peculiarities render them best adapted to their environment. In other words, in the keen competition of life there is a survival of the fittest. The survivors, those best adapted to their environment, will tend to produce offspring in which the favourable characters will be more emphasised, leading gradually and in course of time to great changes in bodily form. Neo-Darwinism holds that natural selection is the main factor in the evolution of plants and animals, and denies the inheritance of acquired characters implied in Lamarckism.

Weismann, a German biologist (1834–1914) propounded the view that there is complete separation between the cells of the body and the germ, or reproductive cells, that the body cells die with the individual and that the germ cells are the only ones passed on from generation to generation; consequently he held that all characters are inherited through the germ plasm and there is no possibility of acquired characters being inherited.

The last of the main views is that of De Vries, a Dutch botanist (1848–1935) who found that certain plants produced offspring different from the parents, and these forms bred true. From this he propounded his theory of evolution by

The young gulls *(Larus canus)* differ markedly from the parents in the colour of the plumage but ultimately grow to be like them.

The formidable nature of the hedgehog's defensive coat of spines is such that only the most resolute dog, the hunger-desperate fox or the sturdy badger will attack it.

mutations. That is by sudden changes, as opposed to the gradual changes implicit in Lamarckism or Darwinism. It is known that new varieties of plants have been produced naturally this way, and in animals mutations have been known to be produced in the laboratory, and under domestication.

The opposing views on the method of organic evolution can be illustrated by many examples. Here are two.

The Darwinists would claim that an ancestral hedgehog had a tendency to roll into a ball when attacked and, coincidentally with it, he developed a few sparse prickles. These two things served to save his life. Of his offspring, some had less of a tendency to roll into a ball, or less pronounced prickles, and in others, purely as a matter of normal variation, both things would be a little more accentuated, and they would tend to escape death and live to perpetuate the race. In time, by the gradual elimination of those less fitted to survive, that is those with the fewest and weakest prickles, the modern hedgehog was evolved.

The mutationists would say the process was not gradual but occurred as a result of sudden changes. Perhaps the truth is halfway between the two extremes.

On the other hand, while the same arguments could be applied to the horn of the rhinoceros, the Lamarckists would say that the horn came because of the habit of butting enemies with the snout. That is, the special structure, the horn, resulted from a habit. There are, it is true, rare cases known of ungulate mammals which, though normally without horns, have developed them as a result of constantly rubbing the head on one spot – but their offspring did not have horns. In other words, we have yet to find a case where it can be proved that characters acquired during the lifetime of the parents are transmitted to the offspring.

CHAPTER III

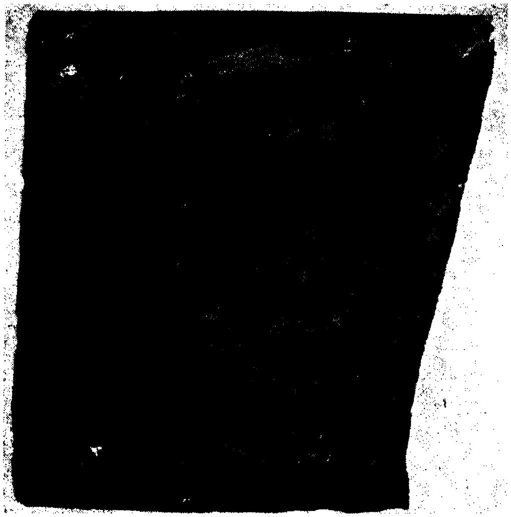
THE HISTORY OF LIFE

THE GEOLOGICAL RECORD

by

DR. W. E. SWINTON

GEOLOGY uses the knowledge that we have of what is going on to-day on the earth's surface to explain the complex structures that were formed in the earth's crust in the past. Every day, as we look around us, we can see change and decay in our natural background, though usually in slow tempo.



We are accustomed to thinking of fossils as the remains of hard parts, bones, shells and the like, but in rare cases the soft parts are preserved. Some of these persist in the form of impressions only. Here is the impression of a large jelly-fish, more than 12 inches across, in limestone.

The wind and the rain, the heat of the sun and the cooling effect of snow and ice, all help to fracture the exposed surfaces of rocks. The debris is carried away on the wind or in the stream. In both of these modes of transport the little particles are used as minute chisels as they are hurried along. The power of a sand blast is well known; and in the rivers the erosion that is done is largely due to the burden that is carried, and pot-holes in the river beds bear testimony to the power of the process. Both the wind and the rivers carry the materials and lay them elsewhere in more or less bedded, or sedimentary, deposits. In time they usually become hardened to form rocks, the nature of which varies with the constituent materials; sands become sandstone, clay gets hardened to mudstones and shales; and many chemical and organic deposits become limestone.

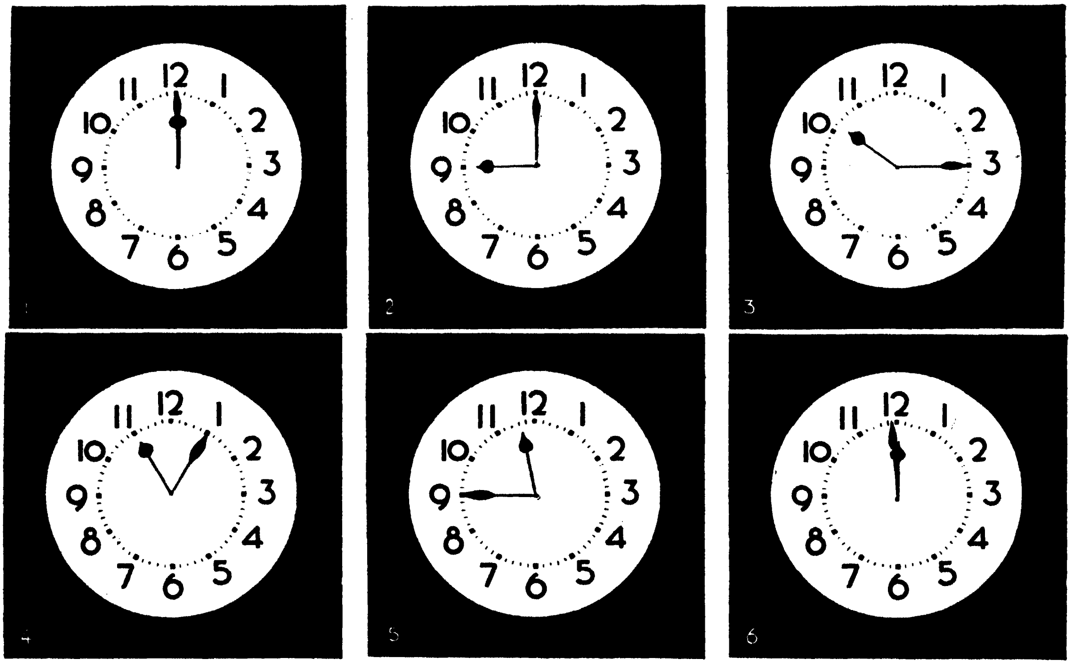
All rocks cannot be classified on this simple plan: for a large proportion of them are not bedded, but are massive and crystalline, such as the granites, the basalts and allied kinds. These are igneous rocks; some from the deeper parts of the crust that have become elevated to, or exposed on, the surface, and others the remnants of volcanic activity of bygone ages. Some are solidified necks of extinct volcanoes whose outer shell has now been worn away. Lava have been poured out in the past and can be seen, old, cold and hardened, often on the surface. These lavas were often poured upon, or injected into, sedimentary deposits and the latter were so baked and altered by the heat that they became recrystallized and "metamorphosed". Similarily, some sedimentary rocks were crushed and greatly modified by the pressure of rock movement in the contracting crust, and by being cracked by mighty earthquakes. These altered rocks of either origin are known as metamorphic rocks.

The igneous and the metamorphic rocks share one important character: they are very unlikely resting places for the evidence of former life. From their origin the igneous rocks can have nothing to do with living things, though some of the lavas may have overwhelmed and destroyed plants and animals. Such remains as might have been included in metamorphosed sediments would be so squashed and ground up as to leave their evidence unintelligible.

When an animal dies there are several things that may happen to the remains. They may be devoured by some other animal. If the animal dies in deep water it may sink into the mud at the bottom and become part of the deposit that is there built up. Obviously, if it has a skeleton its chances of preservation as a recognizable structure will be infinitely greater. On land the sequence of events may be somewhat different. The body may disintegrate and the pieces be scattered; or the remains may be covered by dust and earth, or even preserved by the lime deposits of percolating waters. Otherwise the remains may be washed away by rain, streams or rivers and so become part of the water-laid sediments. In such cases it would hardly be expected that complete skeletons of the vertebrates would be found, for they would almost certainly lose some disjointed part on their way to their final resting place.

Millions of years later, after innumerable vicissitudes, the rock may be opened by erosion, or split in some man-made excavation, and the remains may then be discovered and studied.

In the newest rocks the fossils will be of animals closely similar to those now living; but as the story is traced back the forms become more widely different. Clearly there is a progression of life and the record, and even some of its dates, can be set out. There are, of course, gaps in the sequence, but they do not controvert the evidence or hinder much the unfolding of the tale.



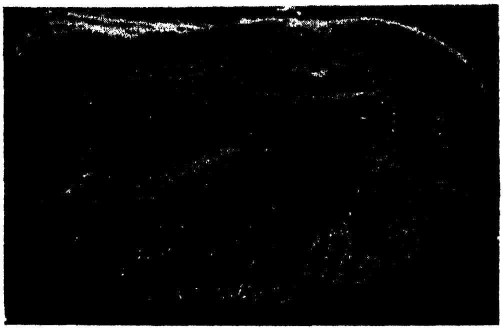
If we take the space of twelve hours to represent the 1,500,000,000 years that have elapsed since life first appeared upon the earth, then the main landmarks could be approximately represented as shown above.
1. Dawn of life; 2. Amphibians appear; 3. Giant reptiles appear; 4. Giant reptiles die out; 5. Modern mammals established; 6. Man appears.

Life probably originated some 1,500,000,000 years ago in the sea. On the other hand, the Cambrian period, in which we first find well-preserved fossils in great numbers, is something like 600,000,000 years old.

The period from 1,500,000,000 to 600,000,000 years ago is represented by rocks crushed and distorted, and almost entirely devoid of fossils. It is known as the Pre-Cambrian, but the Era that it represents is usually known as the Archaen or Proterozoic. This era saw great changes in geography and climate; uplift and depression; outpourings of lava on a vast scale;

and towards its end ice ages. Fossils from it are rarely reported and very seldom seen. Traces of sponges, radiolaria, and even of jelly-fish are said to occur in places. Traces of blue-green algae have been found. These are, however, not all the evidence, for the Pre-Cambrian rocks often have highly carbonized shales and slates and deposits of graphite. There is little doubt that this carbon was derived from the remains of living organisms and that these must have been abundant.

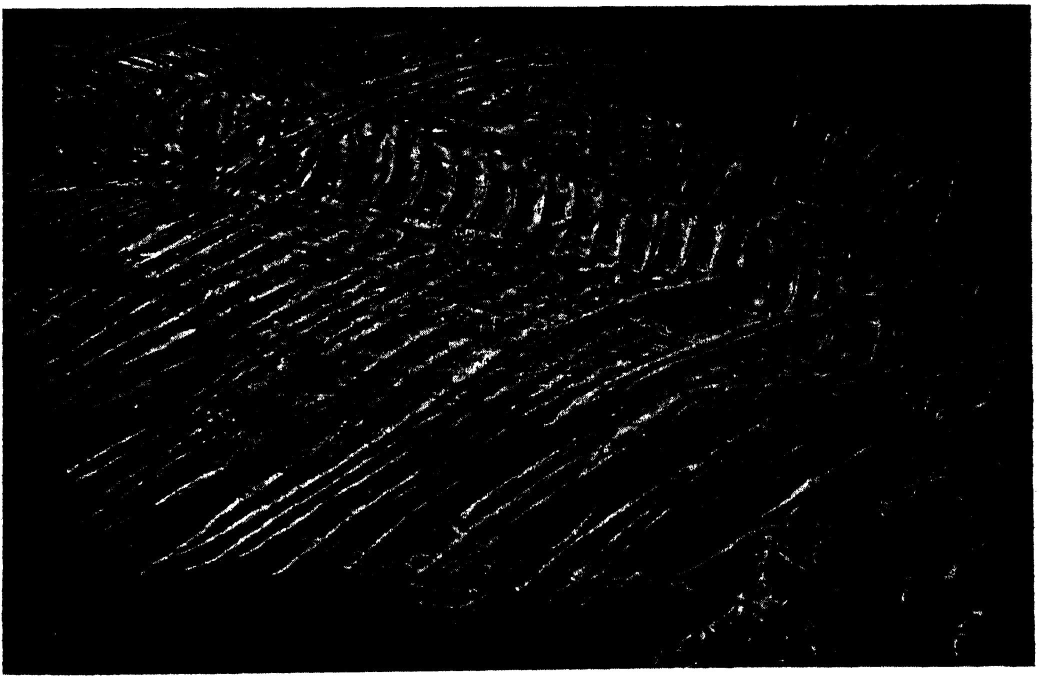
The Cambrian period, the first and well-understood chapter in the geological story, takes its name from the Latin word for Wales, for it is there that the series is very well represented. The period is also well known from other parts of the world, but wherever they are found, the change in the fauna is remarkable. A whole suite of invertebrate forms, many of them with shells, bursts upon the stage of world history. Sponges, worms, brachiopods, molluscs, echinoderms and arthropods are all frequently found.



The fossilized wing of an insect which lived during the Carboniferous Period. This again is an impression only.

Of the arthropods, the trilobites are remarkable for their variety and their armament.

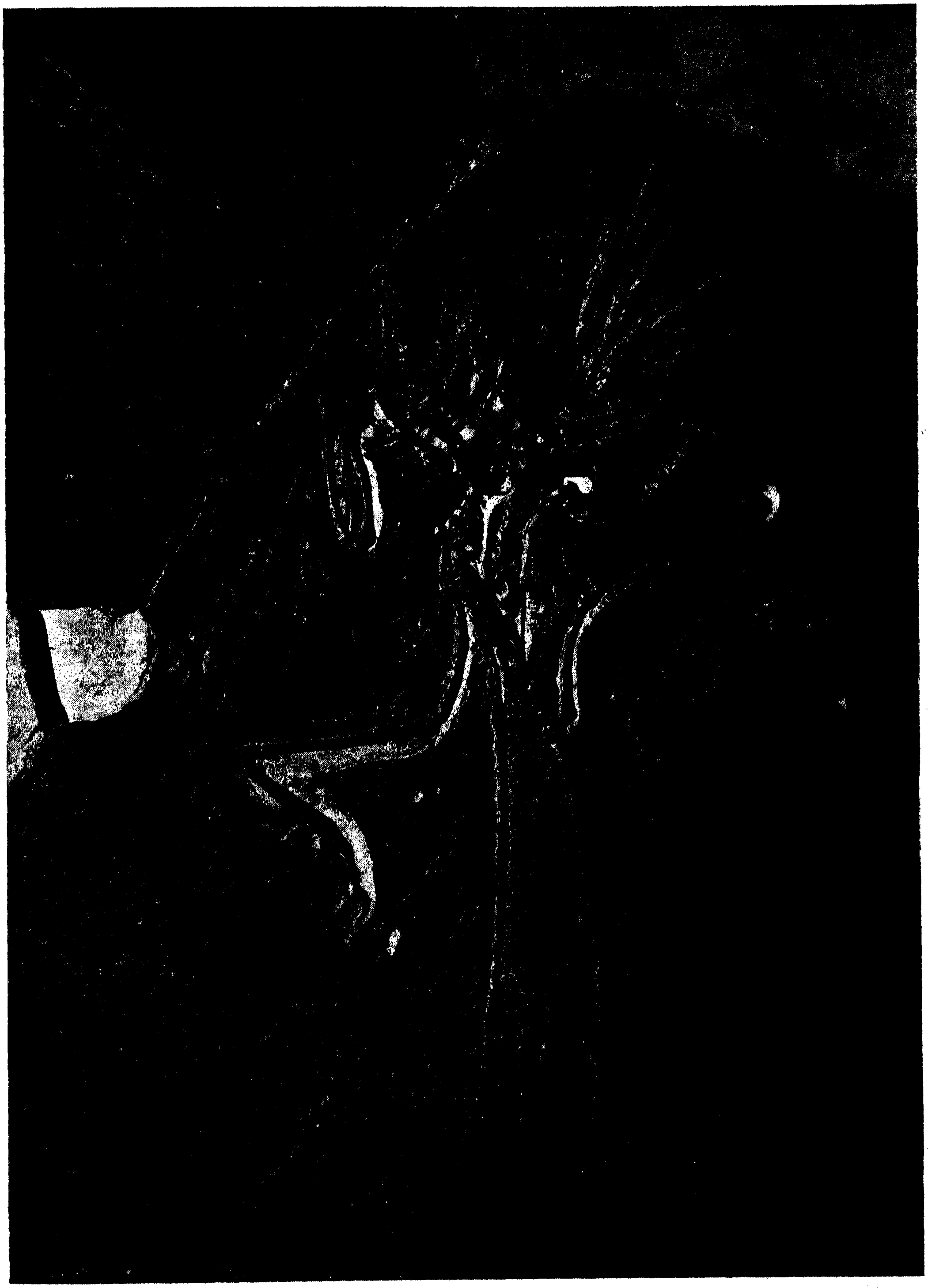
There has been much discussion as to the development of the shell and armour of these Cambrian forms. All the forms are marine and some have argued that the earlier seas probably did not contain sufficient lime for shells to be constructed by the animals: others have suggested that the



The fossil remains of an Ichthyosaur, an extinct aquatic reptile having a fish-like form.
With such information as may be gleaned from a specimen like this, the palaeontologist is able to learn not only what the skeleton was like. By comparison with the structure and habits of living animals he is also able to learn much of the internal structure and habits of an animal he has never seen. Many fossils are much less complete than this, but even so their study has shed a considerable light on the ancestry of animals living to-day.

TABLE OF THE GEOLOGICAL RECORD AND THE SUCCESSION OF ANIMAL LIFE

Era	Period	Number of years ago that each period started	Number of years' duration of each period	Guide to succession of animal life
Quaternary	Holocene	(Present day)	———	———
	Pleistocene	1,000,000	1,000,000	Man appears
Cainozoic	Pliocene	15,000,000	14,000,000	Modern animals established
	Miocene	35,000,000	20,000,000	
	Oligocene	45,000,000	10,000,000	
	Eocene	70,000,000	25,000,000	
Mesozoic	Cretaceous	140,000,000	70,000,000	Giant reptiles dying out
	Jurassic	170,000,000	30,000,000	First birds
	Triassic	195,000,000	25,000,000	First mammals
Palaeozoic	Permian	220,000,000	25,000,000	Giant reptiles appear
	Carboniferous	275,000,000	55,000,000	Reptiles and insects appear
	Devonian	320,000,000	45,000,000	Amphibians appear
	Silurian	350,000,000	30,000,000	Fishes abundant
	Ordovician	420,000,000	70,000,000	Very early fishes
	Cambrian	520,000,000	100,000,000	Marine invertebrates only
Proterozoic and Archaean	Pre-cambrian	2,500,000,000	1,980,000,000	Scattered traces of animals only (mainly radiolaria and sponges)



The evidence of the rocks as the geologist first sees it. (One half national size.)
A slab of limestone bearing the remains of the earliest and most primitive bird known. It is from the Jurassic.

sudden adoption of cannibal habits by one group compelled the others to adopt defensive measures. It is much more likely that shells are part of a physiological process in which the animal has no say; that the lightly armoured forms can overcome their handicap, but the more heavily burdened are doomed to a sedentary existence. At any rate, the lime affected more than the animals for beds of Cambrian rock are composed of the remains of lime-secreting algae.

The two following periods, the Ordovician and the Silurian, still take their names from Wales, as they are named after peoples who lived there. The climate of these times was moderate to warm and encouraged the growth of the invertebrate fauna we have already outlined. These were the days of the marine invertebrates but their dominance was not to last.

Traces of the first fishes have been found in the late Ordovician but only towards the end of the Silurian are they satisfactorily seen in the evolutionary picture; they were strange little jaw-less fishes but some shark-like forms also occurred. They are of tremendous importance in the story for, here at last, are vertebrates. However varied and interesting the invertebrate faunas may be, it is the vertebrates that catch the human eye.

In the next period, the Devonian, there are two phases, a series of typically marine deposits and a non-marine series of rocks that were laid down in flood plains and suffered long intervals of drought. The latter, known as the Old Red Sandstone, make it clear that many of the fishes were no longer marine but were freshwater in habit, and that some of them had developed a lung that allowed them to withstand long spells of drought.

Amphibians, too are now known to have been present.

The tempo of evolution would seem to have been quickening, for in the succeeding Carboniferous period we have the insects, and another vertebrate group, the reptiles, developed. On the lands the vegetation was luxuriant, with great swamp forests. Around the pools the reptiles crawled; in and out of the swamps went the amphibians; in this moist scene the falling trees accumulated to form, long afterwards, the coalfields of the world.

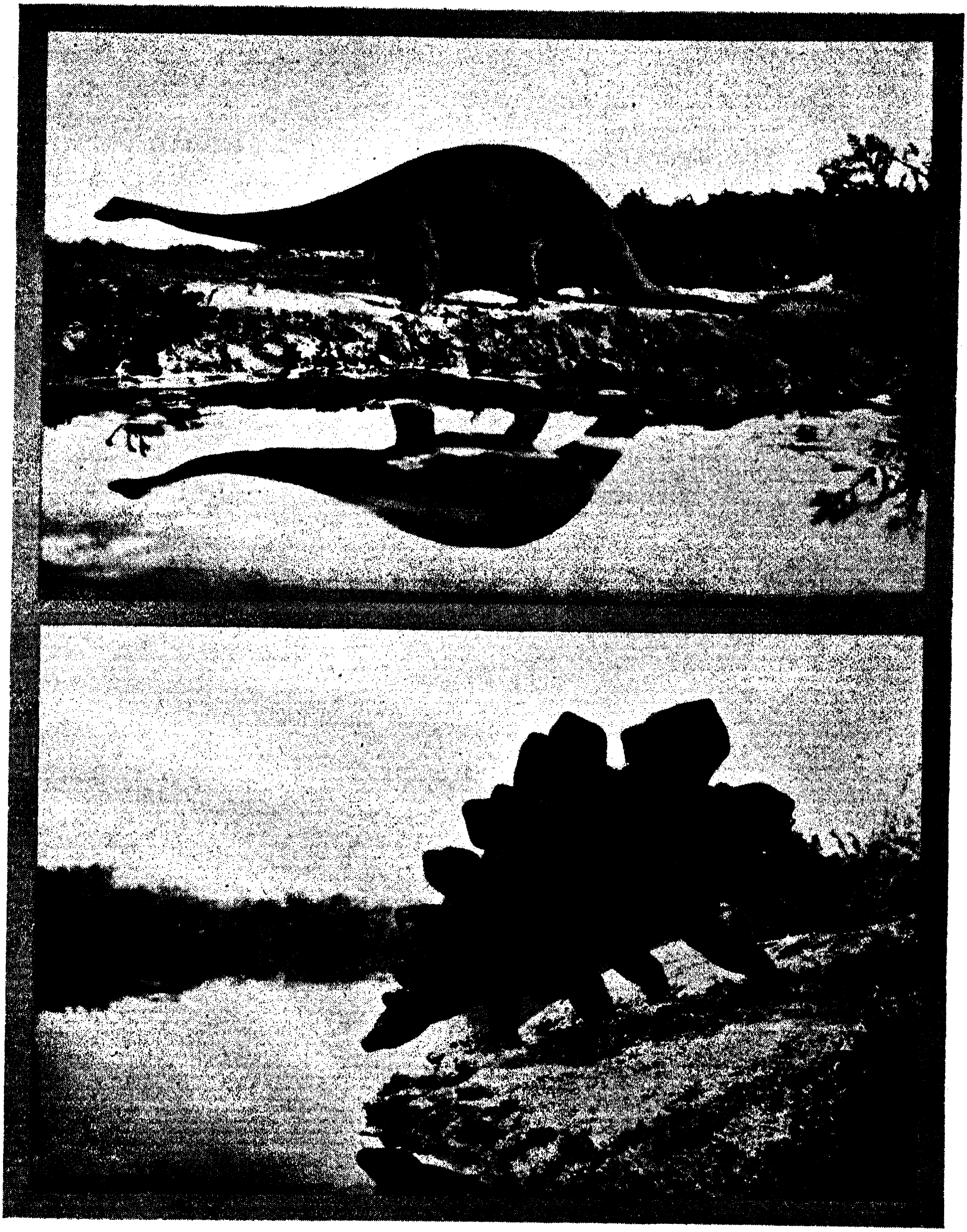
The generally warm Carboniferous period ended in many places with an ice age, and this persisted into the Permian. The latter was a comparatively short period of great evolutionary significance, for in it were developed many land and sea reptiles whose descendants were to be rulers of the world for millions of years to come.

All the periods from the Cambrian to the Permian are included in the Palaeozoic era, the age of ancient life. The next age, the Mesozoic, or that of middle life, comprises three periods, the Trias, Jurassic and the Cretaceous. These are commonly called the age of reptiles, for in this long space of earth history, lasting for about 125 million years, reptiles were rulers in every element. The great dinosaurs were dominant on the land, and the most massive of them, like *Diplodocus*, the largest land animal of all time, were in the pools and the rivers. Reptiles, in the pterodactyls, were masters of the air, and in the waters, freshwater or marine, the swimming reptiles, plesiosaurs, ichthyosaurs and mosasaurs, were very much at home.

Great coiled molluscs, the ammonites, were also in the seas at this time, and on the lands not only reptiles were to be found. Early in the Trias the reptiles had given birth to the mammals and presumably to the birds, though the latter may have been developed a little later. In the Jurassic we find some evidence of both. *Archaeopteryx*, the earliest bird that we know, a reptile-like creature with toothed jaws, but with feathered wings and tail, is of Jurassic age. The mammals, however, were small and unobtrusive and it was not until the late Cretaceous that their presence is important, foreshadowing the appearance of true placental kinds.

During the Cretaceous period the reptiles were beginning to wane and some of the greatest had already gone. Geographic and climatic changes were making themselves felt and at the end of the period, that was also the end of the Mesozoic, the ruling reptiles died out, on land, in the air, and in the waters, leaving no descendants, save the much less impressive forerunners of the tortoises and crocodiles of to-day.

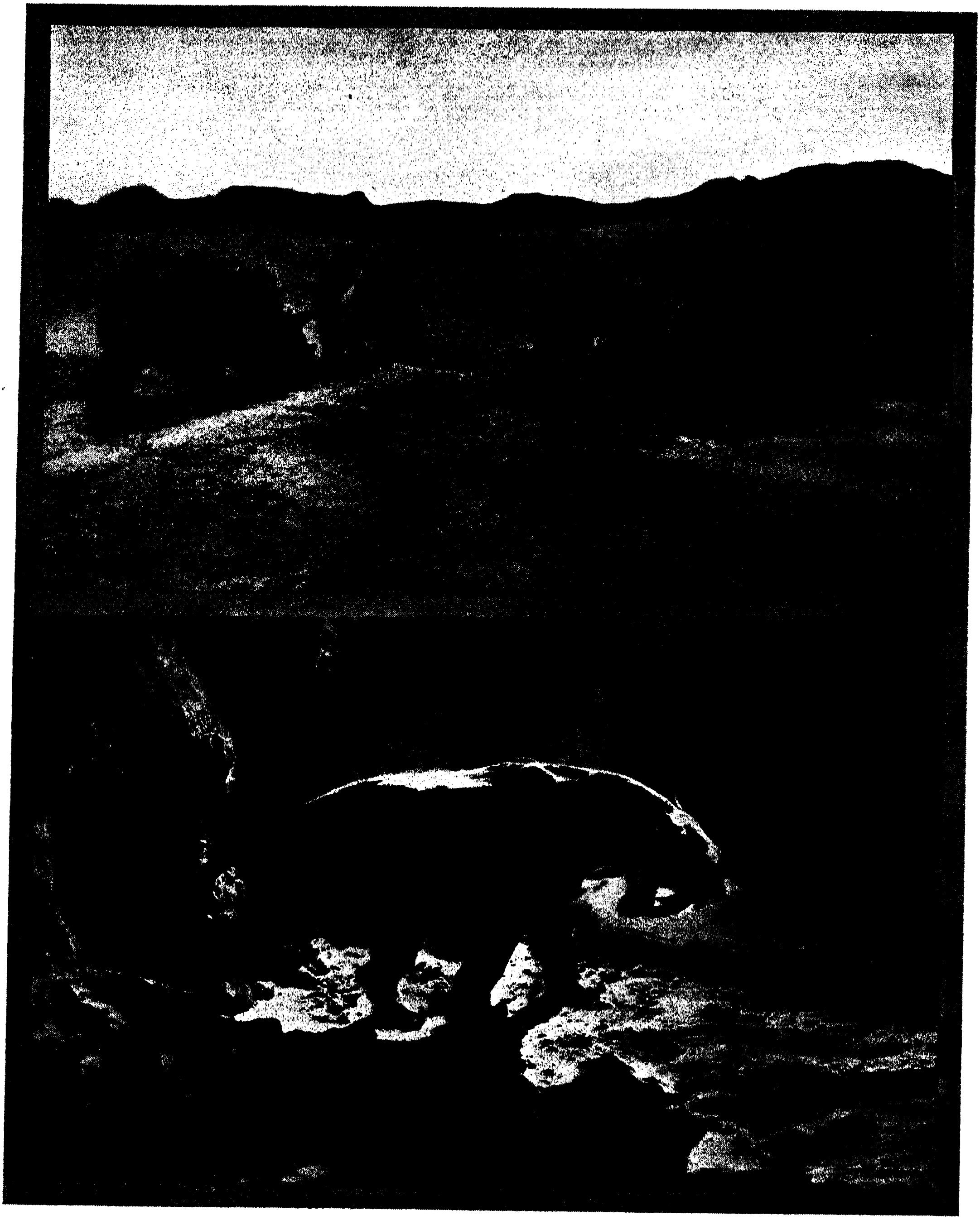
The following era, the Kainozoic or Tertiary, saw the rise of the fauna and flora that we know now. At first these developed grotesque types,



Diplodocus, a reptile living in North America 100,000,000 years ago, was one of the largest animals known. It had a length of nearly ninety feet, most of which was taken up by the long neck and tail. It lived in the swampy regions around lakes and estuaries and fed on vegetation. Slow-moving and slow-witted it must have fallen an easy prey to the more agile carnivorous reptiles which are known to have lived at the same time.

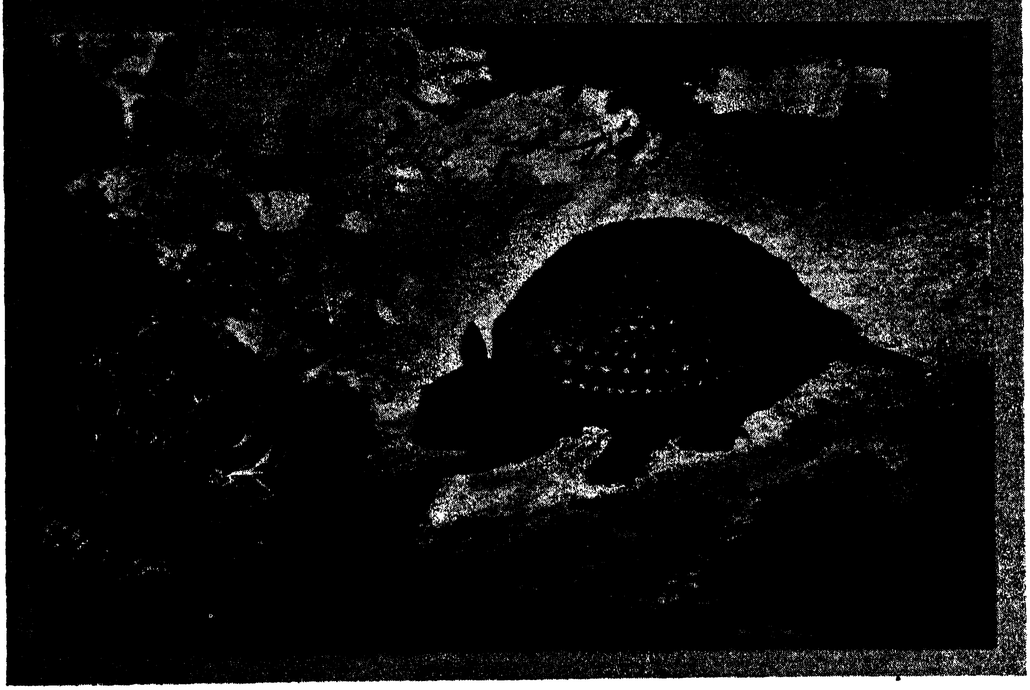
Stegosaurus, twelve feet at its highest point, a Dinosaur living at the same time as *Diplodocus*, was also a herbivore, but instead of the smooth skin of the latter its body is protected by a heavy armour of bony plates.

(Photographs, on pp. 61–63, of restorations by Vernon Edwards.)



Triceratops, another of the large reptiles which used to roam the plains of North America in Cretaceous times. The head is heavily armoured, with a large shield and three horns, the upper of which often measured three feet in length. Like all the giant reptiles the bulk of the body was out of all proportion to the size of the brain. A *Triceratops* measuring twenty-five feet long and standing nine feet high at the hind quarters would have a brain about the size of a kitten's.

The Sabre-toothed Tiger is not a tiger at all. In fact is is only distantly related to the true cats. Heavily built, of the same proportions as a large lion, there can be little doubt that it was carnivorous, though how it used its sabre-like fangs has not as yet been satisfactorily explained. Early man must have been very familiar with this fearsome beast.



Two young bulls of the extinct mammal, *Uintatherium*, of North America. Their skeletons had some resemblance to that of the modern elephant, although their outward appearance recalls more the rhinoceros of to-day. On the head were three pairs of horns, and the males had a pair of dagger-like fangs. They probably fed on the vegetation of the Eocene forests.

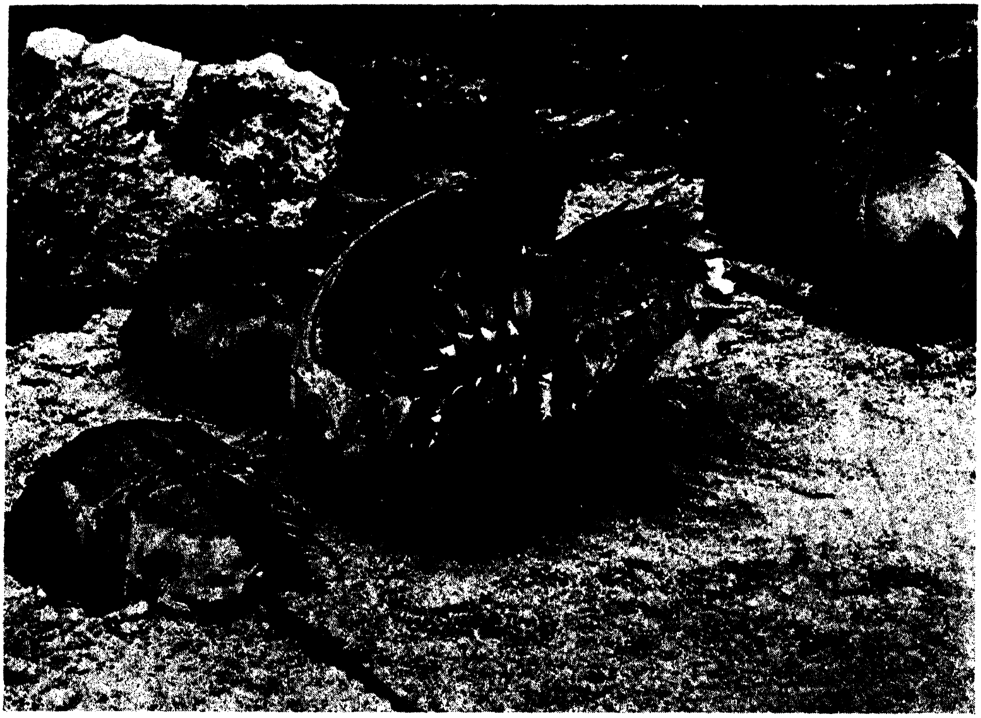
Glyptodon, closely related to the modern Armadillos, lived on the grassy plains of South America in the Pleistocene Period. These twelve-foot long vegetarians probably withdrew the head and legs into the shelter of the bony carapace for defence against enemies.

as if they were following in the dinosaurian tradition, but gradually the scene became less bizarre and the forms of the animals more and more familiar.

Man comes into the scene very late, a mere half million years ago. Historically he is a scratch on the surface of earth history, but in his mental abilities, in the power of receiving and transmitting knowledge and experience, he has begun a new chapter of that history. We call his period the Quaternary and it includes recent times. Looking back over the long series of fossils we can see undoubted evolutionary pathways. There are many missing links it is true; but when we bear in mind the hazards of fossilization, of preservation and of discovery, the tale is remarkably well told.

LIVING FOSSILS

The geological record shows that change is a constant feature of life; one form gives rise to others; there is increase in size, the adoption of other habits and habitats. Yet there are a few forms that have not participated in this change and which, for millions of years in successive series of fossiliferous rocks, have presented more or less the same appearance, though not always in a precisely similar background. Although they are not numerous they have been seized upon by critics of the idea of evolution to show that there are animals that do not react to the process. *Lingula*, a brachiopod, is perhaps the best known of all these kinds. It is to be found to-day in the tropical Indo-Pacific seas, in shallow



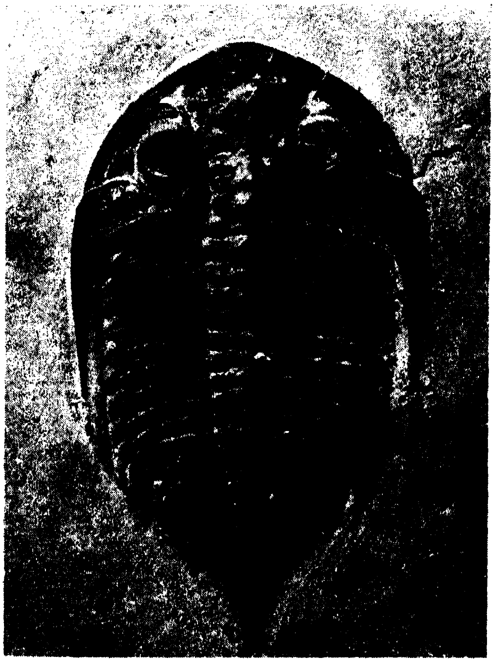
The King Crab or Horseshoe Crab, *Limulus polyphemus*, a heavily armoured marine Arachnid, resembling a crab in appearance but related to scorpions and spiders. The species has survived unaltered from the Silurian seas. Its larva is very like the fossil Trilobites so commonly found in the Coal measures. The King Crab, which is two feet long, including the tail spine, has four eyes, two in the middle and one to each side, on the upper surface of the dome-shaped shell. It is found on sandy or muddy bottoms in the seas of North America, from Maine to Mexico, and off the West Indies. Related species are found off the coasts of East Asia.

waters, where it lives in a tube excavated from the sand. It used to be said that it had persisted from the Upper Cambrian, and there are, of that age, a series of rocks known as *Lingula* Flags that are full of a very similar kind of shell. It is now appreciated, however, that these early forms were not exactly the same shape and were not quite so well adapted for burrowing. They are therefore called *Lingulella*; but in the Ordovician period undoubted examples of *Lingula* occur, and this genus has persisted to the present. The reason is really not hard to find. It is just that *Lingula* has had no need to modify its kind of life and its background.

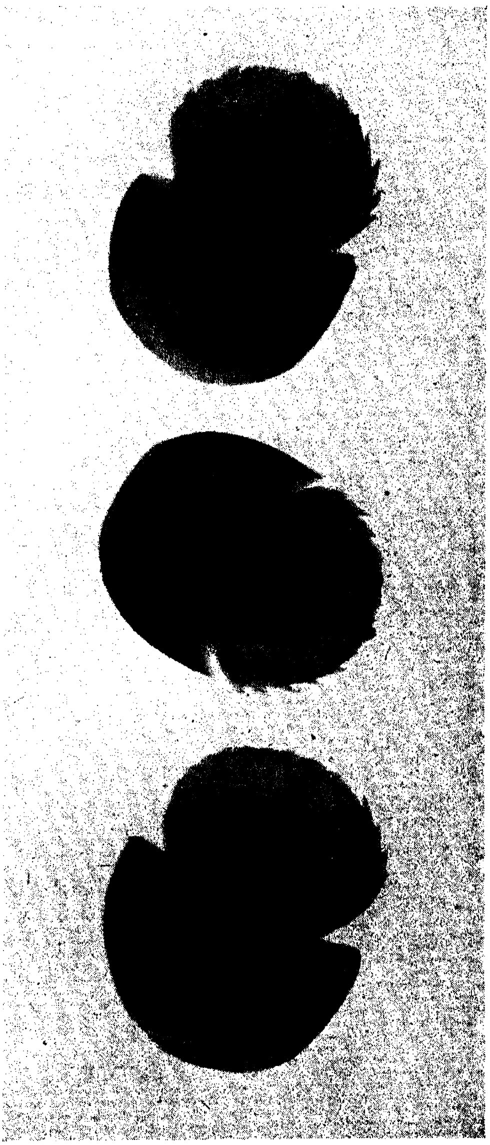
Nautilus, a coiled-shell Cephalopod, has often been quoted as another persistent type from the Palaeozoic, but careful examination shows that the early forms are not identical with the recent, and the modern *Nautilus* is only accepted as a survivor from the Tertiary.

Among the vertebrates there are some well-known survivors from antiquity. Among the fishes some of the sharks have survived for comparatively long ranges. *Heterodontus*, the Port Jackson shark, has continued since the Jurassic, and in this case the persistence may be due to the continued habit of eating molluscs. One or two of the dogfish (e.g. *Galeus*) have also survived from the Upper Jurassic.

One of the most remarkable discoveries ever made concerns a highly important group of the



A Trilobite, one of the primitive Arthropods, from one inch to two feet long, which were a dominant form of life in the Cambrian and Ordovician period.

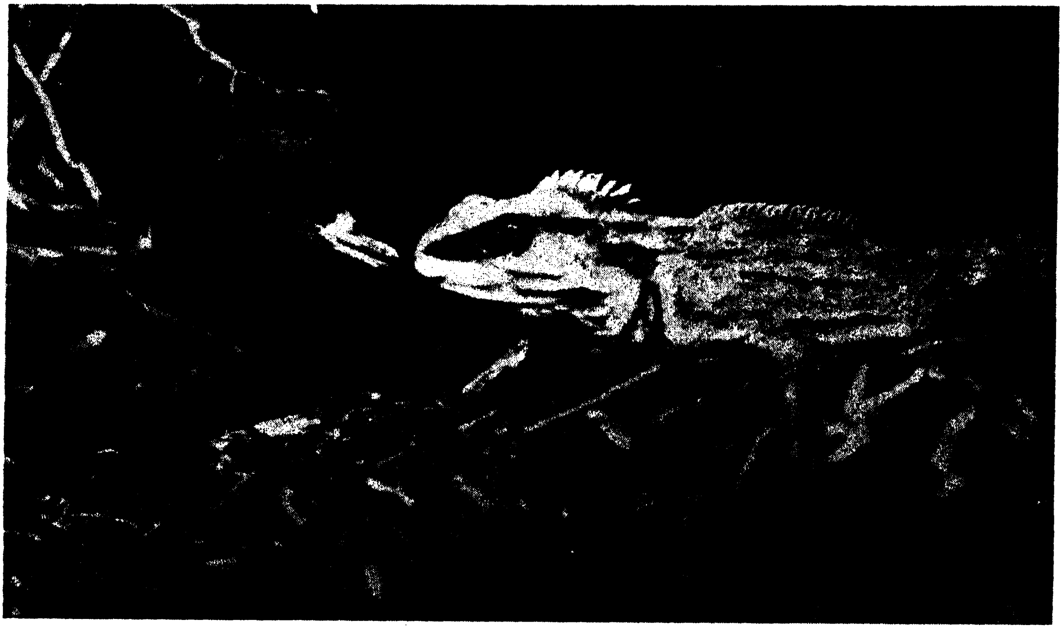


Larvae of the King or Horseshoe Crab. These form an interesting link with the past by reason of their close similarity with the Trilobites. (About 3 times natural size.)

bony fishes, the Coelacanths, which first came into the geological record in the late Devonian and which apparently faded out in the Cretaceous. At least, no fossil remains have ever been found since that date. Yet a few years ago a fishing vessel trawling in deep water off the coast of south-east Africa pulled up a peculiar kind of fish which turned out to be a living Coelacanth. This has been named *Latimeria*, and its survival would appear to be due, in part, to a change of habitat. The original Coelacanths were fresh-water fish, whereas *Latimeria* has apparently taken to the deep waters of the salt seas (see p. 128).

Perhaps the classic vertebrate "living fossil" is the little Tuatara, *Sphenodon punctatum*, now found on certain islands off the North Island of New Zealand. It is the sole survivor of the once great reptilian group of the Rhynchocephalia that has many fossil representatives. It dates from the Jurassic and until some few years ago was common on the New Zealand mainland. It is important because it now shows the structure of the third or pineal eye which was a common feature of so many great fossils. It has a remarkable "home life", for it digs its own burrow and then shares it with a petrel. The bird lives on one side of the living-room and *Sphenodon* on the other. The Tuatara is nocturnal and usually is about two feet long.

As examples of group survival, in contrast to generic, mention should be made of the Chelonia which have persisted from Triassic times with very little modification of any kind. The crocodiles, too, have an ancient lineage, for they arose in the Triassic and have undergone no profound changes.



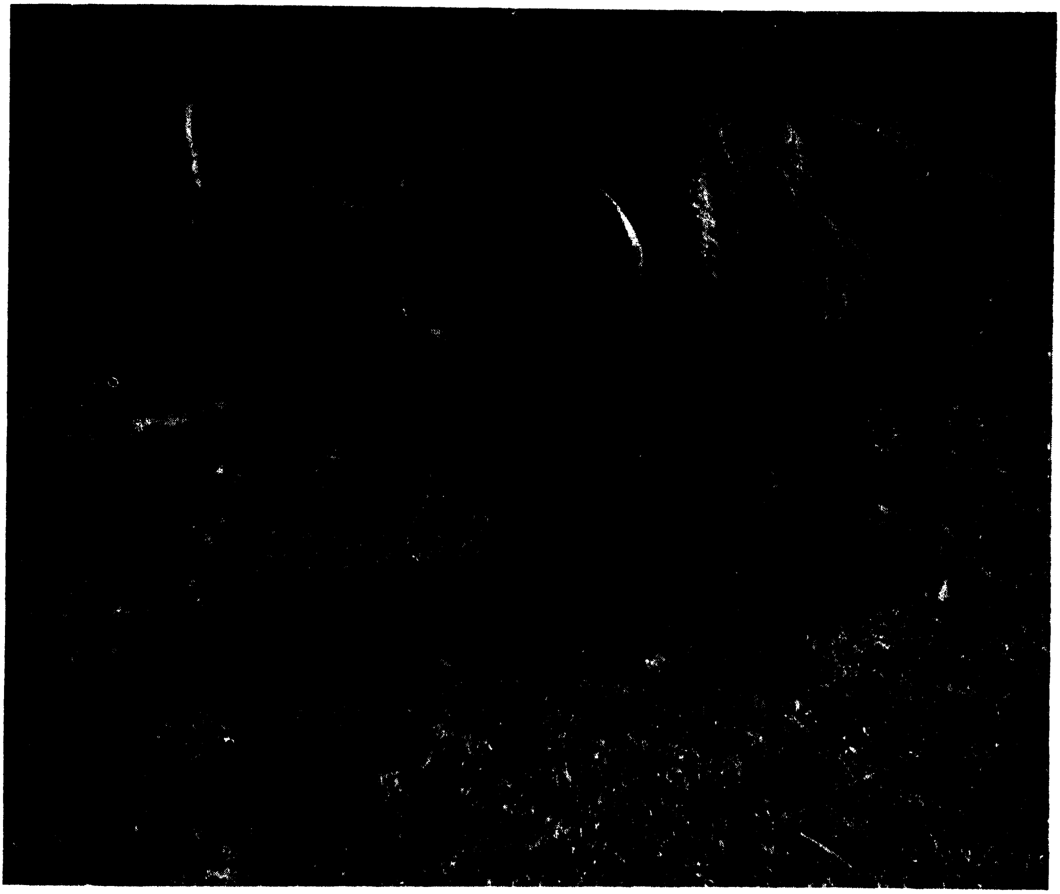
A living fossil.
The Tuatara, the only modern representative of the great reptiles that roamed the earth in the Mesozoic period. It is fast dying out, and now inhabits a few islands only to the north of New Zealand. The Tuataras live in short burrows which they dig, and which they often share with petrels. The female lays leathery-shelled eggs which she buries a few inches beneath the surface of the earth.

The ability to survive would appear to demand a slow and unspectacular existence. The most important progenitors of evolutionary offspring were interesting, but they usually came to nothing after the epoch-making birth. If the survivors have done nothing biologically striking, at least they have persisted. On the other hand, certain habitats are protective, and of these isolated islands are among the most favourable. Thus *Sphenodon* has been helped to linger on, just as the marsupials of Australia have lived on when their relations almost everywhere else have long been gone.

ANIMALS THAT HAVE RECENTLY BECOME EXTINCT

The causes of extinction are fairly well defined and many examples could be quoted from the animal groups of the past. Among the animals that have been known to men similar, if less numerous, examples can be cited. The principal causes are two-fold: those arising from the environment, whether geographic, climatic, or biological; and those arising in the animals themselves, usually physiological.

Changes in the physical environment work both ways – for the isolation of sections of a fauna may protect it; on the other hand, change may permit the entry to a district of new and more advanced competitors, so that changes in the living environment may then come into play. This living environment includes other animals, plants and even man himself. By far the most important of these is man, for he may directly exterminate whole groups of animals himself, or, for his own purpose, he may so interfere with the fauna that what is called the balance of nature is disturbed with far reaching, and sometimes disastrous, results that are apparently indirect. Examples of these phenomena are numerous and interesting. The Moas of New Zealand

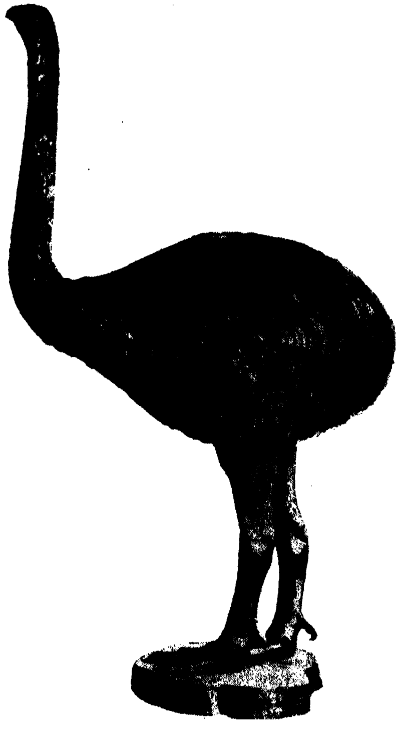


The Bison, or American Buffalo, once existed in its millions blackening the plains as far as the eye could see. Slaughtered for its hide, within twenty years it was almost exterminated. Fortunately a few herds are preserved in the parks of North America.

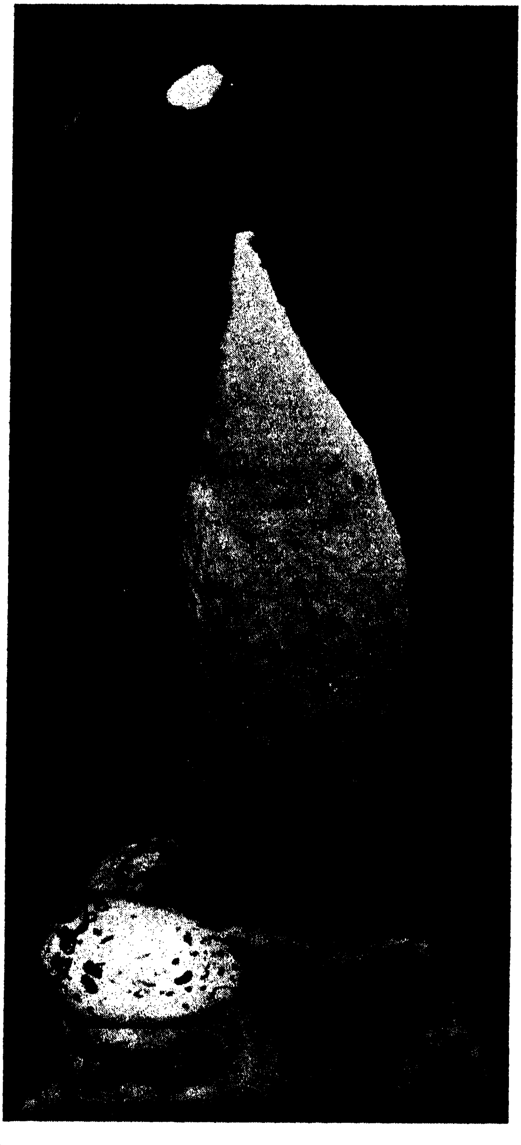
were large flightless running birds, sometimes ten feet high. Remains of them are well-known and the birds at one time must have been abundant. On the coming of man to the islands they provided a ready source of food as their remains from sites of old native camps testify. The Moas were too accessible and so were soon exterminated.

The Dodo of Mauritius, another flightless bird of a different kind, was exterminated much later. This bird was as large as a turkey, but was much clumsier. It was discovered by the Dutch in 1598 and several specimens were brought to Europe. By 1681, however, it was extinct, having been hustled off by the pigs and other animals that had been introduced into the island, as well as having been killed in numbers by men.

The island of St. Helena provides an example of a different kind. It was once well wooded, but the Portuguese, in 1513, introduced goats to these new pastures. The goats found the vegetation very much to their liking and in a relatively short time they had destroyed all the young seedling trees. When the old trees died there was nothing to take their place, and nothing to maintain the soil cover, so that soon the island was barren. This extermination did not, of course, only affect the trees but must have killed off many animals which had their homes among them.



The Moa, a large flightless bird of Australia and New Zealand, which became extinct in historical times.

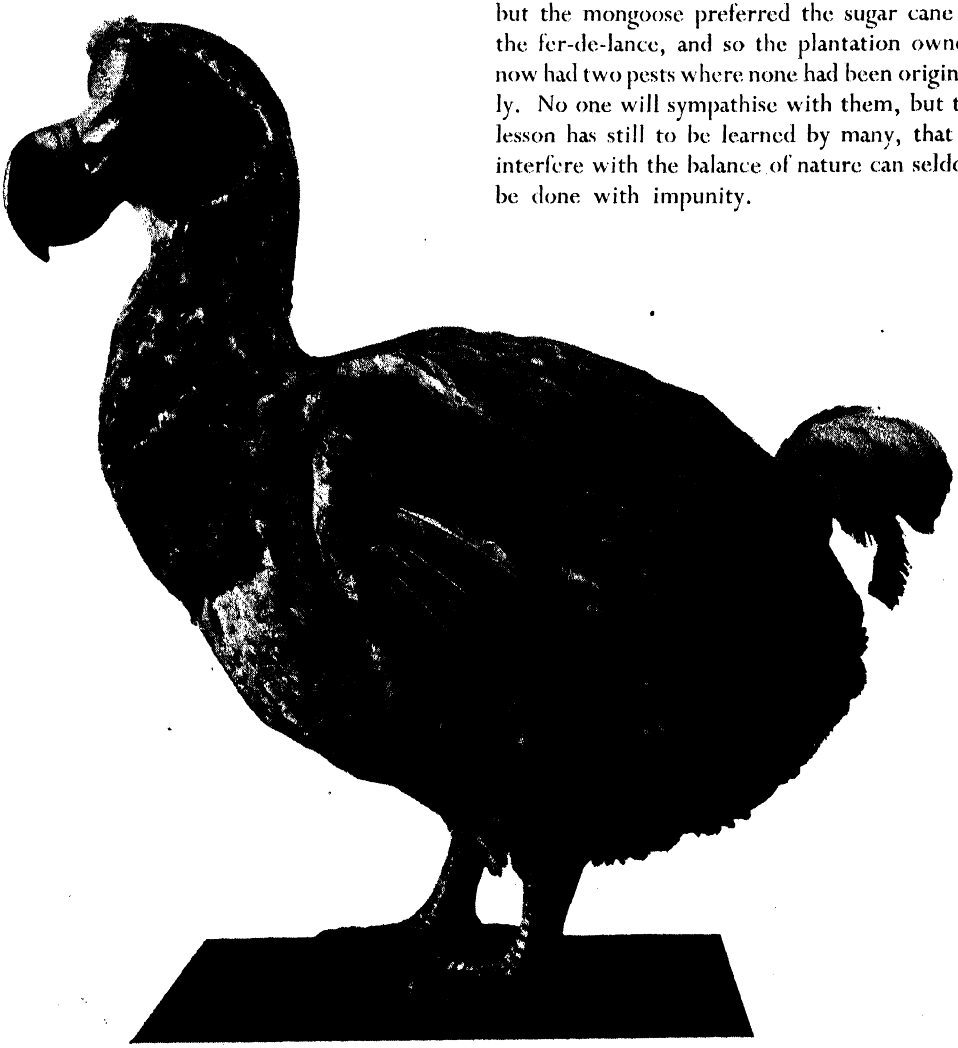


The Great Auk became extinct a hundred years ago. There is fairly clear evidence that it was already declining and that the slaughter of it by man merely hastened its end.

The Australian marsupial "wolf", the Thylacine, was exterminated except in Tasmania in competition with the Dingo. This wild dog was apparently introduced by the aborigines when they arrived from Asia, and the first white settlers found it, wild and fierce, engaged in destroying the indigenous marsupial forms.

Even apparently unobtrusive animals shared a similar fate. One of the Sea-cows, *Rhytina*, which lived in the North Pacific, was wiped out by man about 150 years ago.

Most of such exterminations by man are thoughtless, and it is a sad commentary on human intelligence that they should have occurred. A story will illustrate a bad example of this unintelligent behaviour. When slave labour was employed in certain sugar plantations many years ago, the fer-de-lance was introduced into the surrounding district to deter the slaves from escaping. Soon, of course, the snakes made their presence felt in no uncertain way much nearer the cane than had been intended. So the mongoose was brought in to combat the snake, but the mongoose preferred the sugar cane to the fer-de-lance, and so the plantation owners now had two pests where none had been originally. No one will sympathise with them, but the lesson has still to be learned by many, that to interfere with the balance of nature can seldom be done with impunity.



The Dodo, a flightless pigeon, lived on Mauritius until man visited the island in the sixteenth century. To-day, all we have of the bird are some contemporary paintings and drawings, and a few restorations, such as the one shown here; but the skeletons are numerous and are constantly being dug up on the island.

THE EXTERMINATION OF THE PASSENGER PIGEON

There was once a pigeon in North America. It is no longer there. The most remarkable thing about it was, however, the tremendous numbers in which it existed. Audubon records a flight of them continuing for three days without a break, and for three hours out of those three days he estimated that a billion passed overhead. Ross King, in 1866, saw a flock which obscured the sun for 14 hours and was 300 miles long and 1 mile wide.

A fledgling of the Passenger Pigeon photographed in captivity. There is an important lesson in the loss of the Passenger Pigeon. We are not always as careful with our natural resources, including our wild animals, as we ought to be, and it is worth recalling that when a Bill was proposed in 1857 to protect this pigeon, a committee of the Ohio State Legislature said: "The Passenger Pigeon needs no protection. Wonderfully prolific – no ordinary destruction can lessen them." It became extinct in 1914.
(Photograph by courtesy of the National Audubon Society, New York.)

It is difficult to find a standard for comparison with these mass flights: but that the statements of their numbers were not exaggerated is borne out by other observers. Alexander Wilson, in 1832, estimated a single flock, seen near Frankfort, in Kentucky, to consist of at least 2,230,270,000 birds, and William Bridges, writing in *Animal Kingdom*, has estimated that if each bird consumed a pint of food each day – a fair average – then this one flock alone would dispose of a mass of food far in excess of the bulk required to feed all the men under arms during World War II.

By September 1, 1914, these vast hordes were gone, and the species extinct, and one more name was added to the long list of animals exterminated by man.

The melancholy story of the Passenger Pigeons begins when the first colonists landed on the eastern seaboard of North America. They found a bird which wandered in vast numbers over large areas of the countryside in search of food, and annually migrated sourthwads each autumn, returning northwards each spring. Further details of the bird were: that its food consisted of beechnuts, acorns, chestnuts and such seeds, raspberries, wild cherries and other fruits, even caterpillars and insects; that it nested by the million on the forests, often a single tree containing 100 nests or more; and that frequently the branches of the trees would break under the weight, with dire results to the eggs and young.

We know a little more of their habits, too. The nest, for example, was flimsy, rather on the lines of that of the turtle dove, so that the single egg could often be seen through the bottom of the nest. The incubation period was fourteen days, and during this time cock and hen shared the duties with a regularity in time usually reserved for the clock-watching human. Twice a day the change-over took place, simultaneously throughout the flock, and each time it occurred the noise of the wings of the fluttering millions sounded "like a roaring tornado". Another curiosity of behaviour, linked with the regular change-over, was that during the nesting season at any given moment of the day either all the males would be foraging and all the females sitting, or vice versa.

There is one singular point, that in spite of its enemies, which included mammals as well as raptorial birds, and the fact that a single egg only was laid, the Passenger Pigeon population should have grown to such vast proportions. This is the more remarkable when it is recalled that mortality among young birds from branches broken under the weight of the nests must have been considerable.

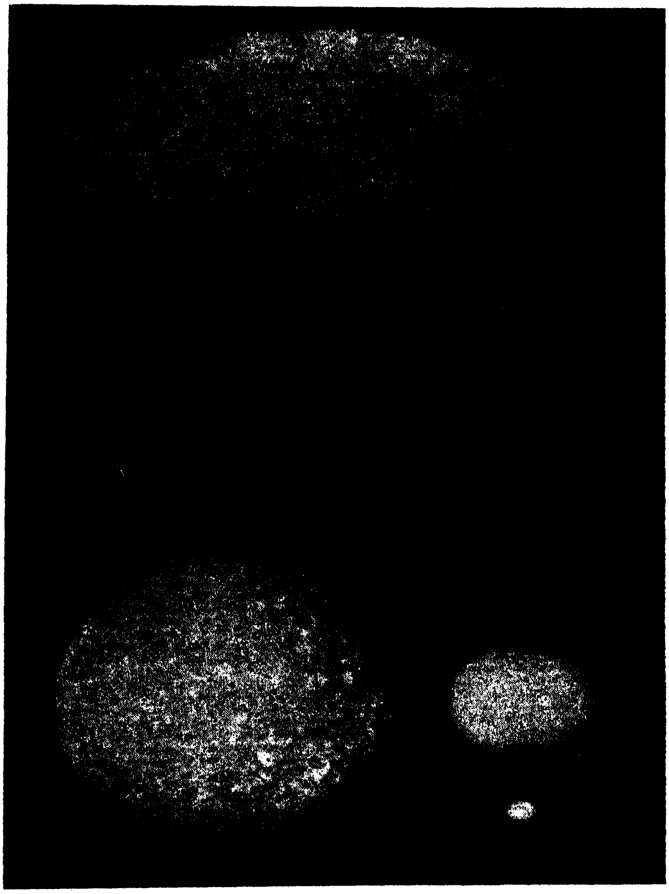
The pigeon was, however, edible; and as the towns grew in the United States of America, there opened up a ready market for its carcase. Even so, its extermination would not have been so readily achieved but for its habits, which gave so great a vulnerability to attack. Its habi-

The Passenger Pigeon, a bird so abundant in America in 1866 that a flock in flight obscured the sun for fourteen hours. It was a long-winged bird with a slender tail, coloured bluish and fawn, with a slate-coloured head and purplish-brown breast.
(Courtesy of the National Audubon Society, New York.)

tual movements in vast flocks of densely packed ranks meant that the most indifferent marksman with a gun could bring down twenty or thirty with one pull of the trigger, and by using a small swivel cannon 200 could be assured at one discharge. Further, they could be clubbed or netted with the greatest of ease; 3000 at a time in one sweep of a net has been recorded. There was, however, an even easier method of getting them, by cutting down the trees, especially when the young squabs were about. Man seems to have lost all sense of proportion in his attack on the Passenger Pigeon, for, not content with these methods of easy slaughter, it became the custom to fell one tree so that in falling it brought down others.

The numbers of the pigeon were still apparently unimpaired when Ross King wrote his description in 1866, but by 1870 the slaughter was beginning to be felt, and by 1880 onwards the birds were disappearing rapidly. The climax appears to have been reached in a massacre at Petoskey, Michigan, in 1878, when at least 300 tons of birds were slaughtered in a few weeks. By 1895 killing for market was finished; in 1906 the last wild bird was caught in the U.S.A.; and in 1907 the last one was caught in Canada. Fortunately, the Cincinnati Zoological Society, in about 1878, bought four pairs of Passenger Pigeons. These were put on exhibition, and the last survivor died in the Zoo at Cincinnati on September 1, 1914, at 5 p.m.

Of the many species of animals that have become extinct within the span of years covered by human history, this is the only one of which we know the exact time of death of the last surviving individual.



The egg (A) of the extinct *Aepyornis*, nearly a foot across, compared with the eggs of (B) an ostrich, (C) a domestic fowl and (D) a humming bird.

RARE ANIMALS

The late Professor Dendy used to tell how in 1901 he was taking a walk along the shore near Christchurch, New Zealand, as the tide was out, when he saw a small nondescript object lying at his foot. He took it back to the laboratory, where it lived in the aquarium for several hours. This animal, now known to us as *Pelagohydra mirabilis*, is probably the most remarkable Coelenterate (see page 149 *et seq.*) ever to be seen. It consisted of a single spherical polyp, little more than an inch in diameter, bearing numerous long slender tentacles, with a tubular mouth also surrounded by tentacles. The structure is most unusual and too complicated to describe here. The main thing to be stressed is that this specimen of *Pelagohydra* is the only one of its kind ever to be seen. It is, in every meaning of the word, "rare".

Animals normally spoken of as rare are not usually quite so seldom seen as *Pelagohydra*. It is, therefore, worth while to consider what exactly we mean when we use this word.

The Sea-lilies (Crinoids: see page 182) of the present day are the descendants of a group of animals which flourished exceedingly in former times. Some of the older rocks are composed almost entirely of their remains and there can be little doubt that in the earlier geological periods they were both numerous and of a large size. By contrast, until fairly recent times, sea-going expeditions brought back so few specimens of recent sea-lilies that is was believed they were both rare and of small size as compared with their fossil relatives. Then the American naturalist, A. H. Clark, who made a particular study of them, completely altered our views. On one expedition in the North Pacific, the ship on which he was the naturalist had her decks covered with several tons of Crinoids, brought up in the nets, on more than one occasion, and of the tens of thousands of individuals so caught many were larger than any known fossil form.

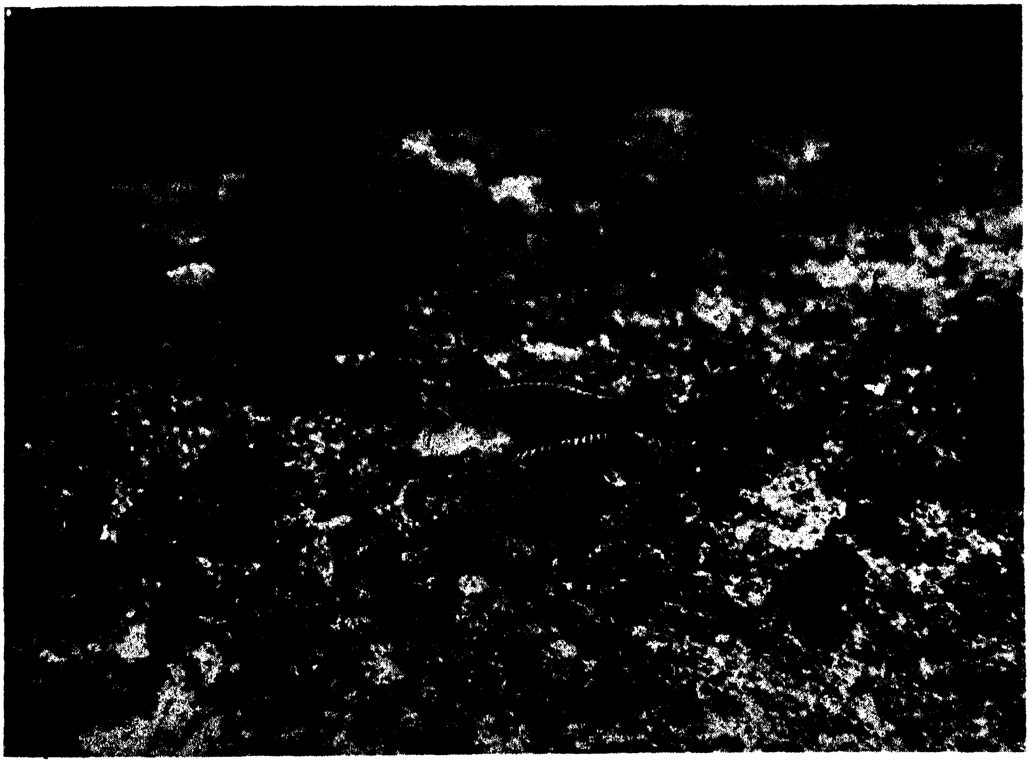
It is such experiences as these which suggest that when we speak of rare animals we can only mean one of two things. Some species are rare – truly rare – because they are dying out. Other species are spoken of as rare – and, indeed appear to be rare – largely because we do not know how, when or where to look for them. So we come to the general conclusion that the word "rare", as applied to animals, must be used with great caution. For example, the three-toed sloth was regarded at one time as a rare animal, yet Mr. Paul L. Swanson, who had the opportunity of studying this animal in its native forests of Central America, found that it was in reality quite numerous, but because it was so beautifully camouflaged, and largely nocturnal in habit (and doubtless also because nobody had made the special effort to look for it), it had been looked upon as, comparatively speaking, rare. Another example is seen in the False Killer (*Pseudorca crassidens*), a whale reaching nearly twenty feet in length. This was first described by Sir Richard Owen in 1846 from a skeleton found sub-fossil in the Lincolnshire fens. Sixteen years later a school of about a hundred False Killers appeared in the Bay of Kiel and from animals stranded then the external form was described. Similar strandings have occurred all over the world since, often in considerable numbers: "several hundreds on Chatham Island in 1906; about 150 in the Dornoch Firth, Scotland, in 1927; over 100 near Capetown in 1928; 167 on the Island of Velanai in 1933; 75 along the east coast of England and Scotland in 1935; and in the same year and at very nearly the same time a school of between 200 and 300 at Mamre, 50 miles from Capetown" (from *Giant Fishes, Whales and Dolphins*: Norman and Fraser). Although *Pseudorca* has been seen in such numbers from the Atlantic and Pacific coasts of North and South America, and from Tasmania and India, in addition, there is no record of its having been seen at sea. Presumably *Pseudorca* would be regarded as rare but for the habit of committing mass suicide on the shore. Given some other species that did not get itself stranded, it could be numerous, yet so little known as to be classified as rare.

CHAPTER IV

THE EXPRESSION OF LIFE

THE MEANING OF BEHAVIOUR

EVERYBODY knows what is meant by behaviour, yet it is the most difficult word to define. Fundamentally, behaviour may be construed as the expression of life, and in using the word we limit its meaning to include the particular aspect to which we wish at that moment to apply it. In other words, behaviour can mean a variety of things and we interpret its meaning according to the context in which it is used. Thus we may give it a wide all-embracing connotation when we speak of the behaviour of living matter; a narrower meaning when we speak of the behaviour of a species. We may speak of the behaviour of a community of animals, of a group, of an individual; the behaviour of a single organ. Or we may refer to physical, emotional or psychological behaviour. As with all departments of the living world, we can visualize it as a complicated machine consisting of an infinite number of cogs, ranging from large to infinitesimally small. We can study the action of each cog separately, yet all the time

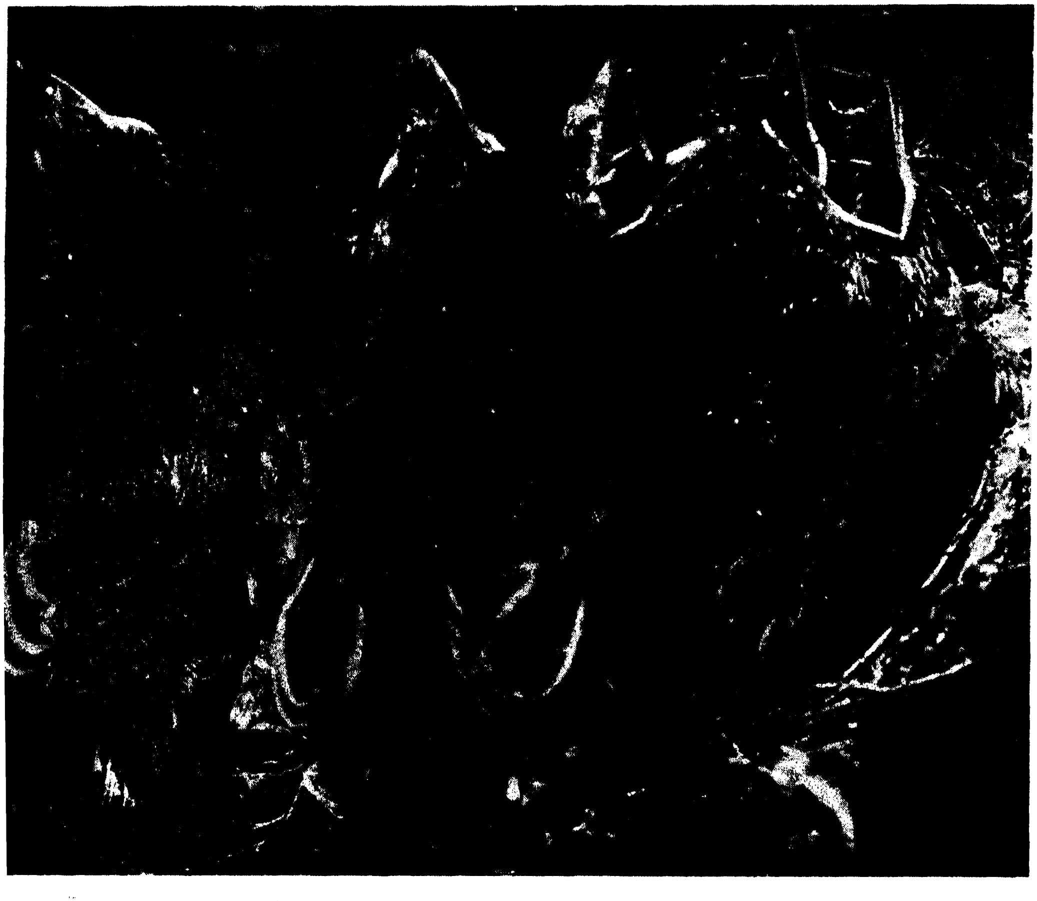


The Razorfish *(Xyrichthys psiltacus)* makes a bowl of fragments of coral, with a sandy bottom. When alarmed it dives into the bowl and buries itself in the sand. All members of the species behave in this way, and the building of the bowl as well as the action of hiding in are determined by a chain of instinctive actions, arising from within the individual. *(Courtesy of Fish and Wildlife Service, U.S. Department of the Interior.)*

we must keep in mind that each cog is dependent upon the workings of every other cog, and its working must be related to that of all the rest.

THE SIMILARITY OF BEHAVIOUR IN ALL ANIMALS

For the present we may limit consideration to the day-to-day behaviour of animals and seek to understand the influences which govern the actions and movements of the individual. In order best to interpret these, it should be borne in mind that there are two sets of activating motives underlying the behaviour of all animals. The first set of these are operative throughout life, from the fertilization of the ovum until death, and may best be described as the constant reaction to the environment, the continual interplay of chemical reactions within the body, and the appreciation of the world through the senses. After hatching or birth, according to whether the animal starts life in an egg or within the maternal body, the second set of three come into play, namely the search for food, the urge to reproduce and the instinct for self-preservation. The first of these last three is operative from birth or hatching onwards until death, the second starts at sexual maturity, reaches a peak and dies down to reach a low ebb as age increases, and the third is largely linked, both as to time and intensity, with the reproductive phase. There may be differences of opinion on this last point, so it may be well to point out that childhood, or, better, infancy, is a period



Young finches in the nest open their mouths as the mother bird alights on a nearby branch bringing food. Their behaviour is the result of a hunger reflex.

A young Puma cub.

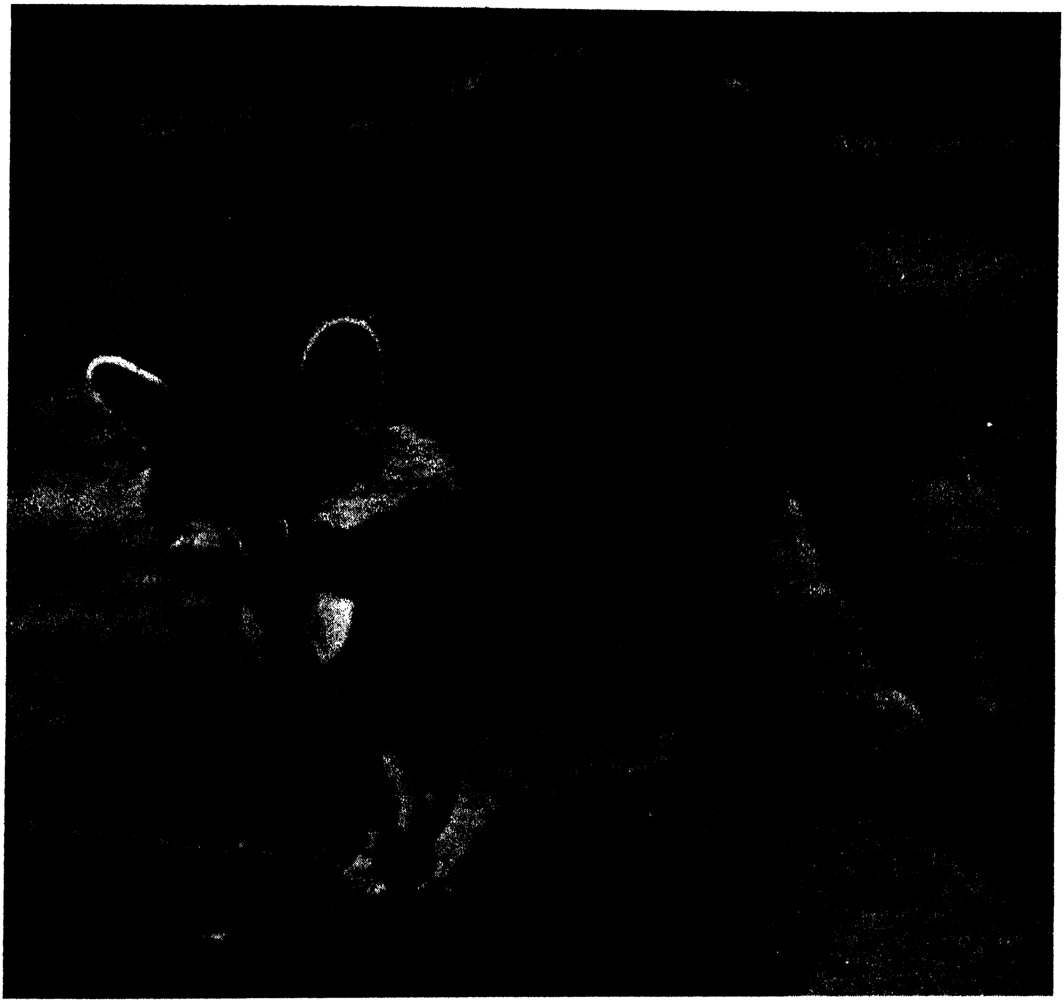
The docility and friendliness of young animals probably has an evolutionary sequence, carrying with it a survival value. If young pumas were as savage as adults, without their experience, they would probably tear each other to pieces in infancy, and the species would soon become extinct. In other words, the docility of the young affords time during which they learn how to live together.

devoted mainly to learning how to live. It is a period in which, in higher animals, play is a conspicuous feature of the daily life, with fear, the stimulus which arouses the instinct of self-preservation, coming in later as the result of experience.

The friendliness of the young Koala probably has an entirely different meaning from that of young lions. It may serve as a means of keeping the infant near its parent for protection.

We are now in a position to recognise yet another cycle (or cog) in the mechanism of behaviour, namely that arising from the phases of growth. The life-time of all individual animals can be divided into infancy, youth, maturity and old age. None of these is sharply defined; each merges imperceptibly into the other, yet owing to the changing balance in the effect of the two sets of activating motives distinct behaviour patterns can be recognised for each phase. Another aspect of behaviour to be kept well in mind is the historical, or evolutionary. For our present purpose this may be dealt with under three headings. The first concerns the evolution of physical characters, the second, the evolution of the psychological factors, and the third, in which these two can be related to the lifetime of any individual animal.

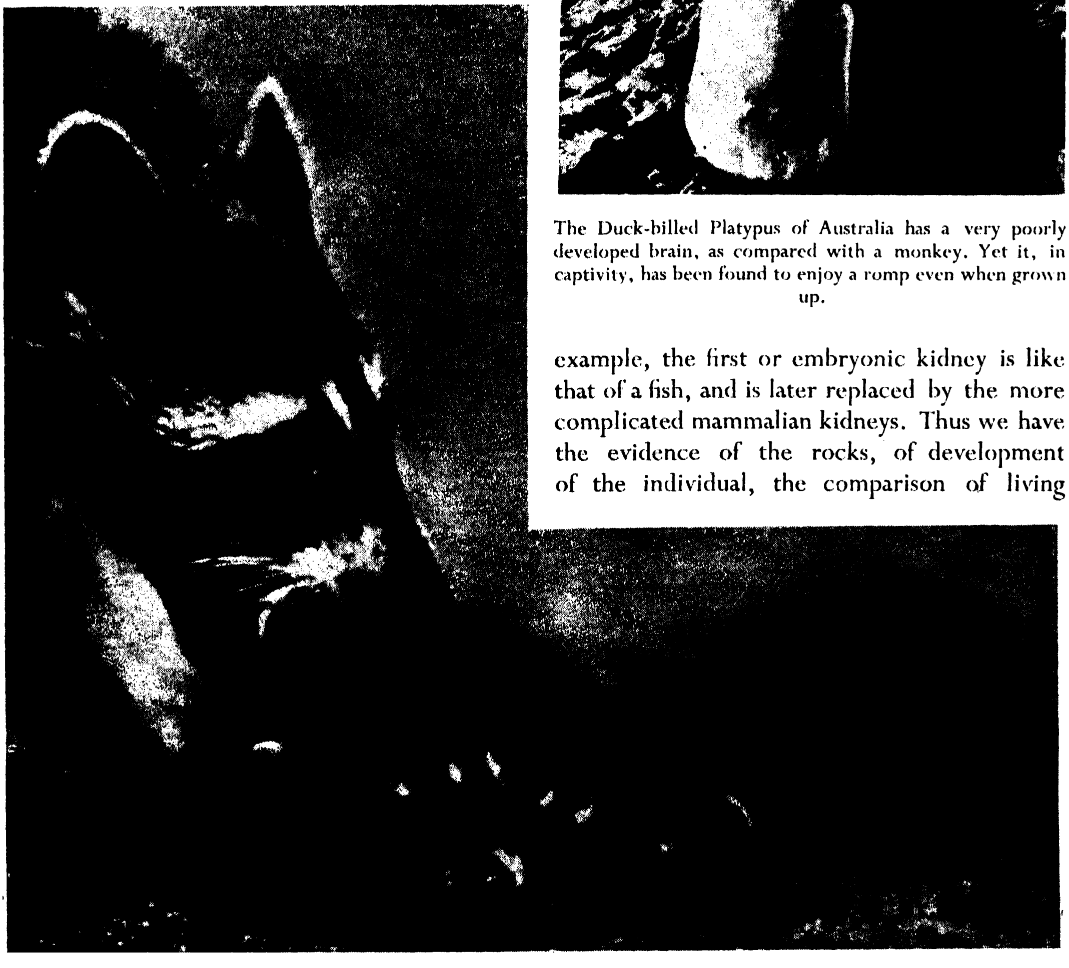
It was a happy accident that gave us Amoeba as the universally-accepted standard for a living organism. Had the early biologists been more aware of the lower forms of life, had their microscopes been more efficient, they would have felt compelled to accept a lower, more primitive standard, which would have been considerably less convenient for purposes of comparison. Amoeba is so nearly like the ovum from which all animals start that it gives a highly convenient starting point for all purposes of comparison. The evidence of the succession of life on the earth shows many gaps, but there are clear indications that as we go from the older to the newer the sequence of animal life has become progressively more highly organised. Together with this there is the strong suggestion that, putting it very briefly, the evolution of the animal kingdom proceeded from the unicellular (the Amoeba-type) to the simple multicellular, consisting of a simple sac with a single opening and a two-layered wall (the Coelenterate-type: see p. 149), to the wormlike, with body divided into segments and with three layers of tissue, to the fish-like and finally the higher animals. At all stages there were offshoots which specialised in their own way. Moreover, at no stage has any one general type died out, with the conse-



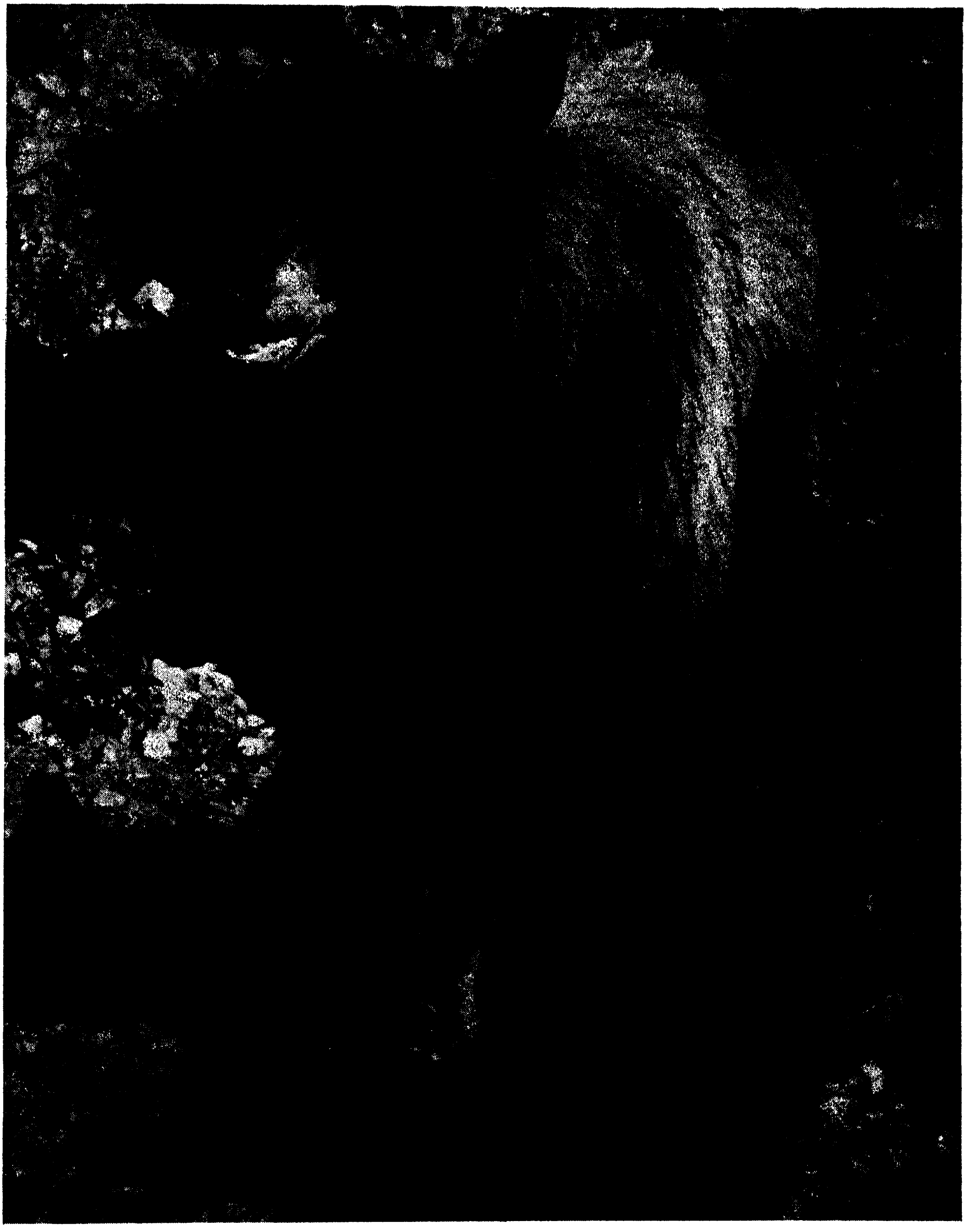
A raccoon washing its food. It is a habit of raccoons to wash all the food given them before they eat it.

quence that to-day there are representatives of all these types still living. Side by side with this we see that every animal tends to recapitulate the stages leading to its present form. Thus, the Coelenterate passes from the unicellular ovum to a multicellular double-layered larva, and ends as an organism consisting, essentially, of the double-walled sac with a single opening. At the other end of the range are higher vertebrates which pass from the unicellular ovum, through the gastrula or Coelenterate stage, through the segmented worm and fish-like stage to the present stage. In the same way, also, the internal organs indicate how the sequence has progressed. In the higher vertebrates, the mammals, for example, the first or embryonic kidney is like that of a fish, and is later replaced by the more complicated mammalian kidneys. Thus we have the evidence of the rocks, of development of the individual, the comparison of living

The Duck-billed Platypus of Australia has a very poorly developed brain, as compared with a monkey. Yet it, in captivity, has been found to enjoy a romp even when grown up.



The mother Raccoon interrupts the play between her two babies to carry one of them off to a new place. Play in young animals is a method of developing the muscles and the senses.



Bears in the Wild Animal Reserve in the Grand Teton National Park, Wyoming, U.S.A. These bears, like those kept in zoological gardens, become very tame and playful, their antics being very like those of young human beings.

animals themselves and the development of the individual organs all pointing in one direction. Now for our second division, the evolution of behaviour. As we pass through the range of living animals from the simplest to the highest, as well as when we trace the changes in the lifetime of an individual, we see that the evolution of behaviour accords closely with that seen in the physical characters. In other words, and this brings us to the third division, behaviour can only be interpreted reasonably in the light of a welding of the evolution of both the physical and the psychological. Just as organs may arise and disappear again at some stage in an animal's development, as for example, the primitive kidney in mammals, so certain aspects of behaviour may appear in the young and disappear as it reaches maturity. For example, certain features of behaviour in human children can only be explained in terms of the behaviour of primitive men. Equally, just as there are vestigial organs so there are vestigial types of behaviour. In man these come out mainly when the emotions are deeply stirred. Typical examples are having the "hair stand on end", the snarling and gnashing of teeth in uncontrollable anger. Moreover, and here is one way in which a study of behaviour supports the hypothesis of organic evolution, many actions and patterns in the higher animals which we include

A group of Cape Penguins.
Penguins sometimes play by climbing up the icy slopes and sliding down on their backs. It is difficult to see any deep meaning in this but it may have a physiological value.

A Black Bear cub of North America, a relative of the much larger Grizzly Bear.

under behaviour can be traced back down the animal scale, growing less marked as we proceed. Or, looked at the other way, we can trace not only the evolution of species or the evolution of specific organs, but an evolution of behaviour.

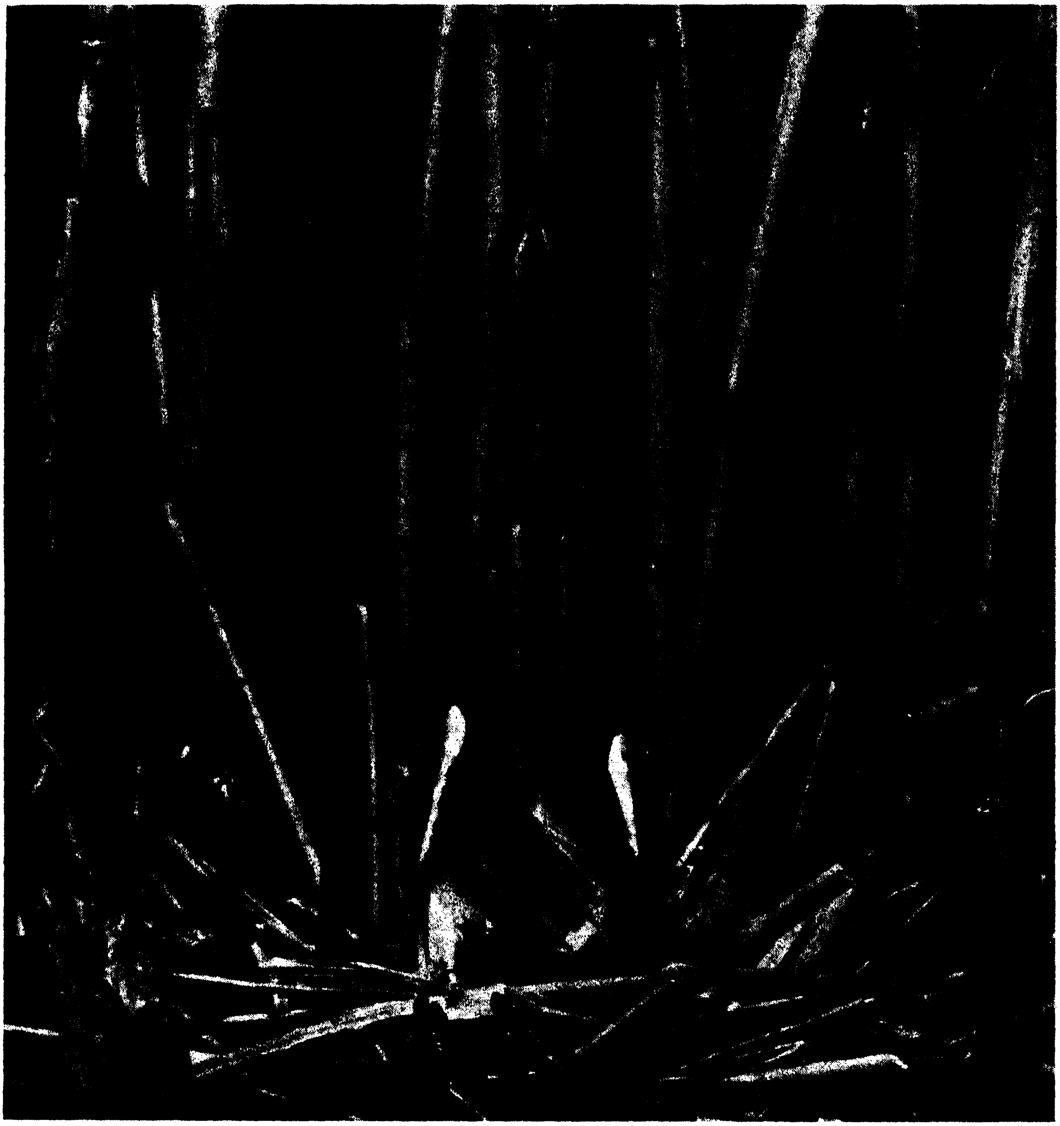
THE ANALYSIS OF BEHAVIOUR

The analysis of animal behaviour involves several initial difficulties. In the first place, those who study it are sharply divided on a fundamental issue into the mechanists, who maintain that all behaviour is capable of being resolved into mathematical or mechanical terms, and the vitalists, who believe that behaviour can be largely interpreted in this way, but that there is something of a vital nature over and above this. The second difficulty is that we cannot get into the minds of animals and see the world as they see it; we can only observe and seek to interpret from known standards of human behaviour. The third difficulty is that of observing the behaviour in a manner as close to the natural as possible. If we turn over a stone and watch the millepede lying under it, we are watching an animal whose whole world has suddenly been transformed by the disturbance, and whose behaviour will be, as a consequence, unnatural. Fourthly, to observe animal behaviour as accurately as possible means long and patient watching, with the need for numerous checkings, further observation and, often, experimental work to corroborate the field observations. Fifthly, a direct consequence of the last, there has grown up a most extensive literature on the subject, and because of this and the sixth difficulty to be dealt with in a moment, any student of behaviour is confronted with a vast tangle of evidence to unravel. Sixthly, behaviour itself is a complex of tropisms, reflexes and instincts, with, in the higher animals at all events, emotions and reason coming in to confuse an already difficult study.

After a drink of warm milk the young skunks curl up to sleep. Born without the protective coat of long hair, which they will grow as they get older, the instinct is to curl up und huddle togeher, so that the heat in the body is conserved and the young animals are kept warm.

The only course open in compiling a book of this sort is to define the terms used and to illustrate, where possible by examples, as the narrative proceeds through ensuing chapters.

A tropism is the involuntary reaction of an organism as a whole to the influence of an external stimulus, in such a way that the consequences of the stimulus shall become symmetrically distributed throughout the body. Since tropisms are dealt with more fully on pp. 85–94, a single example must suffice at this point. Jumping spiders are actively busy when the sun is shining and disappear as if by magic if a cloud obscures the sun. In other words, the whole body is stimulated to activity by intense sunlight and

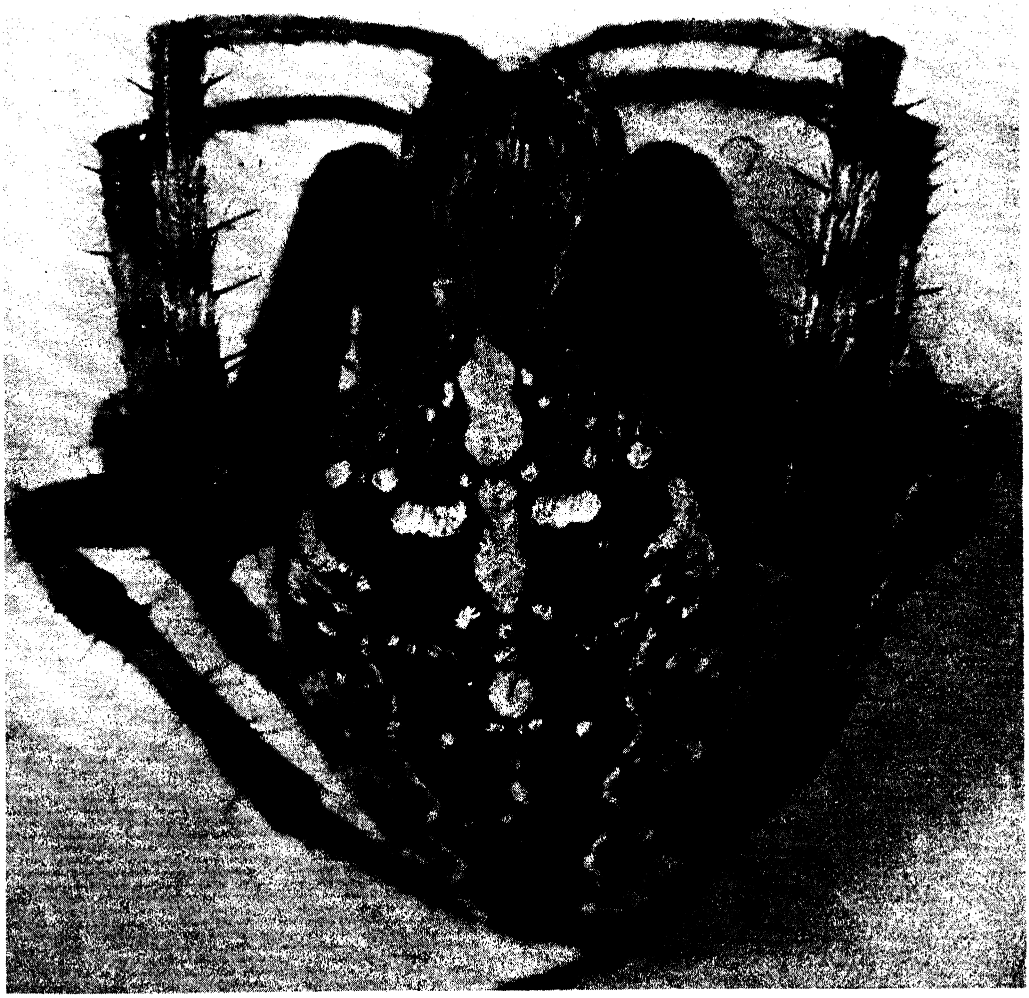


The Bittern *(Betaurus stellaris)* is an adept at concealment. When disturbed it stretches the neck, beak pointed upwards, and stays motionless, so that the dark stripes running down the neck feathers blend with the reeds among which it hides during the day. The Bittern, related to the Heron, haunts the marshes at night feeding on insects, fish, especially eels, and the smaller animals of the marshes. It is found throughout Europe and most of Asia, but in the British Isles has been almost exterminated by the egg collector.

the spiders are said to be positively heliotropic. (Unfortunately, to the difficulties enumerated above must be added another, the confusion of terms. For heliotropic some people use the word phototropic, others heliotactic, and others photopositive.)

A reflex action, on the other hand, implies an automatic response to a disturbance in the environment acting through nerve cells and can consist of a single action, as a blink of the eyes, or a series of actions, as in breathing. It may be involuntary, as in the secretion of saliva at the sight of food, and all animals of the same kind exhibit a reflex in the same way when subjected to the same stimulus. In addition, a reflex involves a part of the body only. Moreover, since a reflex is an adjustment, by muscle and nerve due to an inherited mechanism, no experience is necessary for its performance.

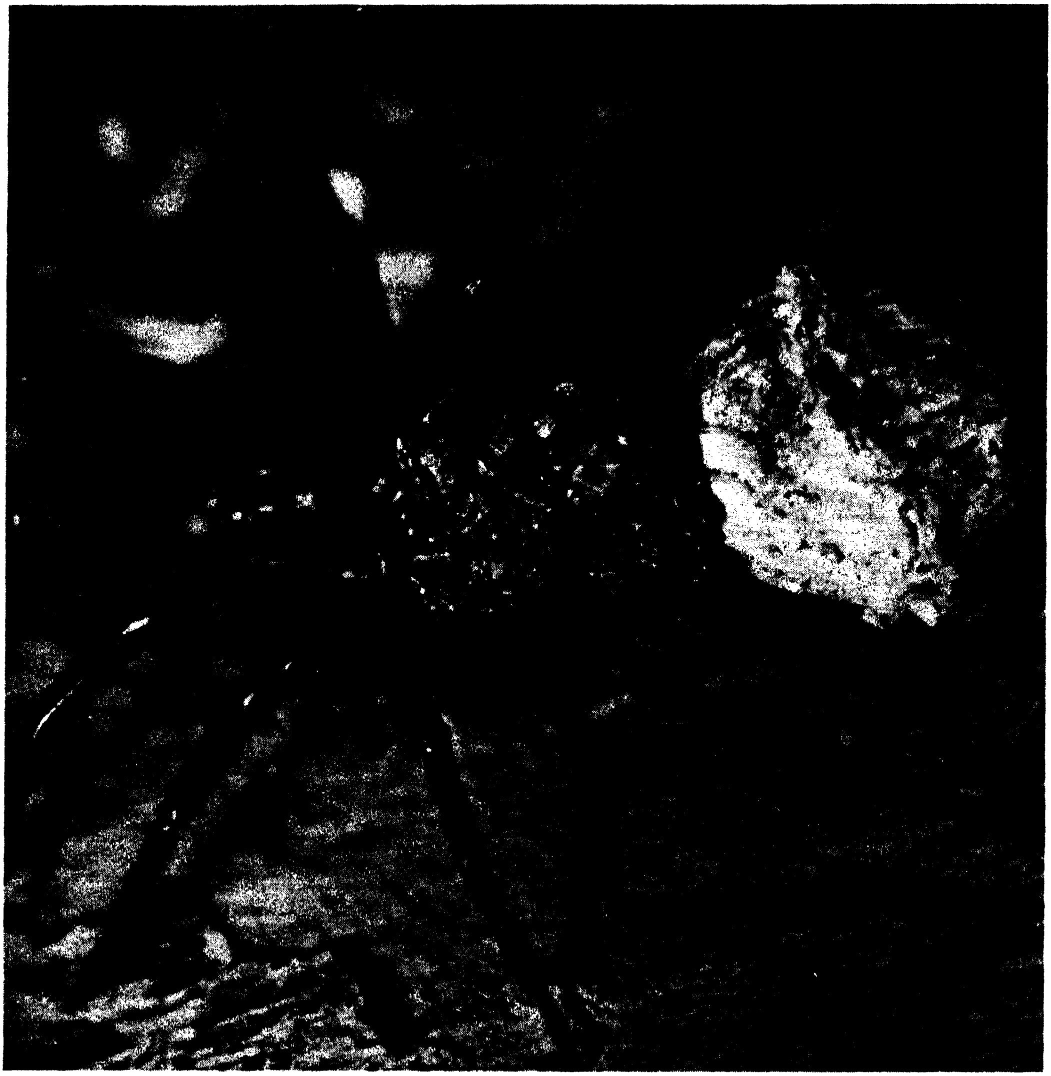
A conditioned reflex is one in which response is obtained when, after the stimulus having been repeated a number of times, only part of the original stimulus is given. Pavlov, for example, found that by ringing a bell when feeding a dog



The Diadem Spider shamming death, when disturbed. At first sight this looks like an intelligent action, but experiment has shown it to be a reflex over which the spider has no control. It is purely mechanical.

a point could be reached when the ringing of the bell alone was sufficient to make the dog's mouth water.

There is no simple definition of instinct. Indeed, it is a concept which must be expressed by enumerating those things which go to make it up. Thus, instinctive actions do not have to be learned and are performed in the same way by all members of the same species and sex. Also, they are performed by the organism as a whole and can be directed towards a distant objective and usually consist of reflex acts following one another in predetermined and unalterable succession. Instinctive action differs from the use of reason in that it is not competent to deal with new situations or with situations out of the ordinary. Moreover, it does not improve with repetition.



A female wolf spider photographed just as the newly-hatched young are crawling from the egg case on to her back, where she will carry them about until they are old enough to look after themselves. A wolf spider carries the egg sac attached by silk threads to her abdomen. So strong is her instinct to do this that if the egg sac is taken from her she will take the nearest thing that resembles it, such as a wad of paper or cottonwool, and fasten that to her body.

TROPISMS IN ANIMALS

by

THEODORE H. SAVORY, M.A.

The moth flies to the lamp, eels glide across the grass to rivers, rag-worms live in tubes or burrows, young spiders climb up gate-posts, wasps find their way to the jam. These are examples of behaviour known as Tropisms, or sometimes as Taxes.

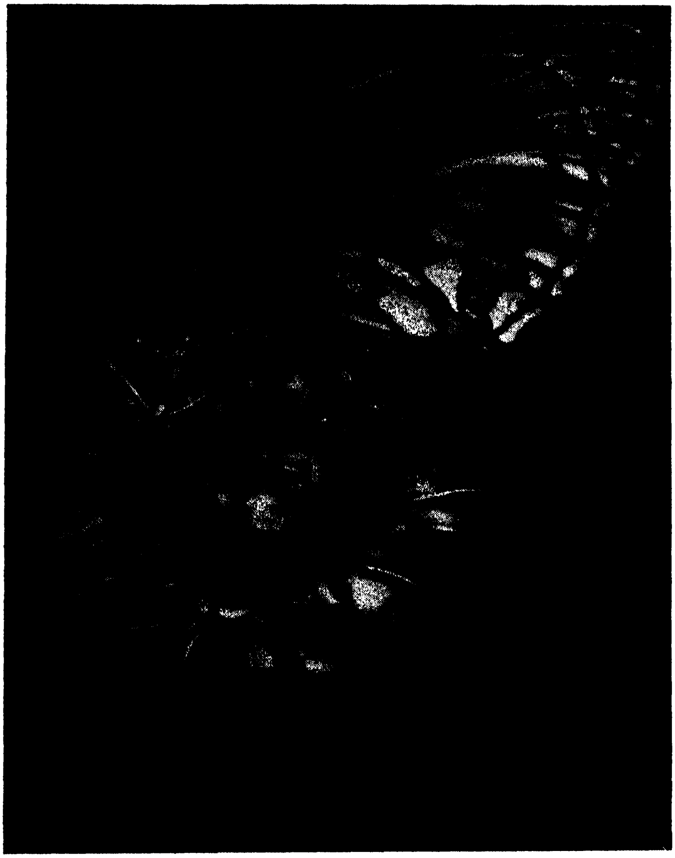
Tropisms were first studied by botanists, who described the turning of leaves to the sunlight as heliotropism, the downward bending of roots as geotropism, and growth towards water as hydrotropism. As will be seen, there is an underlying resemblance between these activities of the living plant and the more numerous and more complicated types of tropistic behaviour in animals. We might be inclined, perhaps not unreasonably, to explain the wasp's entry into the jampot as a wish for sugar or a liking for its taste; we might, rather less reasonably, explain the spider's climb as a preliminary in its object of migration: but interpretations of this kind, dependent on desires and purposes, are not very helpful when we look at the singed body of the moth, which has achieved nothing; and cannot be applied at all to turning petals and twisting roots, where effort, desire, purpose and consciousness are presumably lacking.

A more acceptable explanation of such movements is a physico-chemical one, based on laboratory experiments. When the light of the lamp falls more brightly on one eye of a moth than the other, there is a greater stimulus of the illuminated than of the shaded retina. It is believed that certain compounds, products of photo-chemical reactions in the retina, diffuse through the moth's body, but, because of the unequal stimuli, in a greater concentration on one side than on the other. These compounds affect the rate of contraction in the muscle-cells which move the wings: hence the wings on the brighter side beat more slowly, and the insect is turned round until it faces the light-source. The illumination of the eyes is now equally intense, a symmetry of stimulus and of its consequences has been attained, and the insect flies straight ahead—to its doom. It has gone not where it wished or intended to go but where its wings have taken it.

Certain characteristics in this way of describing an animal's behaviour are obvious. First, it is unnecessary to consider the animal's purpose, of which we know little, or its desires, of which we know less. And if we may neglect these, we may neglect "mind" or consciousness altogether, a not unwelcome course since it is nearly impossible to get any information about the "thoughts" or events in the "mind" of a starfish or a barnacle. Further, it is possible to study tropistic responses under laboratory conditions, and to confirm the physico-chemical

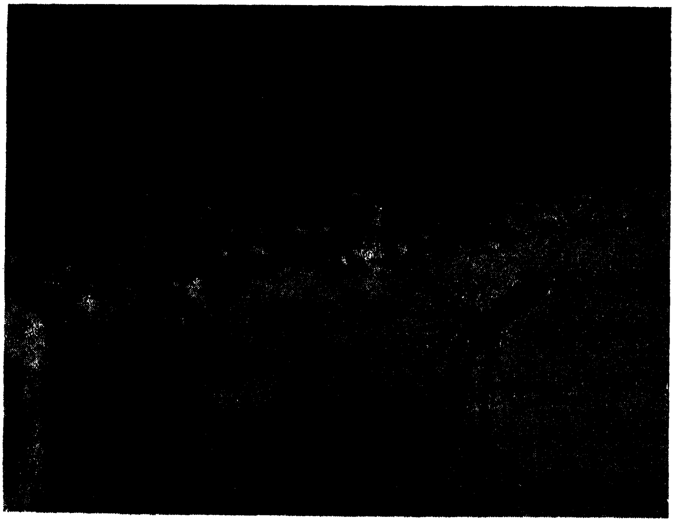
A sample of plankton magnified.
In the sea vast movements of billions of minute organisms, the plankton, take place daily. At night they swarm at the surface, during the day, especially when sun is bright, they migrate to the deeper layers. These daily migrations are the result of a negative heliotropism. (Magnified 5 times.)

explanation by determining whether the familiar laws of chemistry can accurately describe and foretell the animal's behaviour. If a study of tropisms suggests that an animal behaves as if it were an unconscious chemical machine, it seems necessary to determine at least how far this view may be justified.



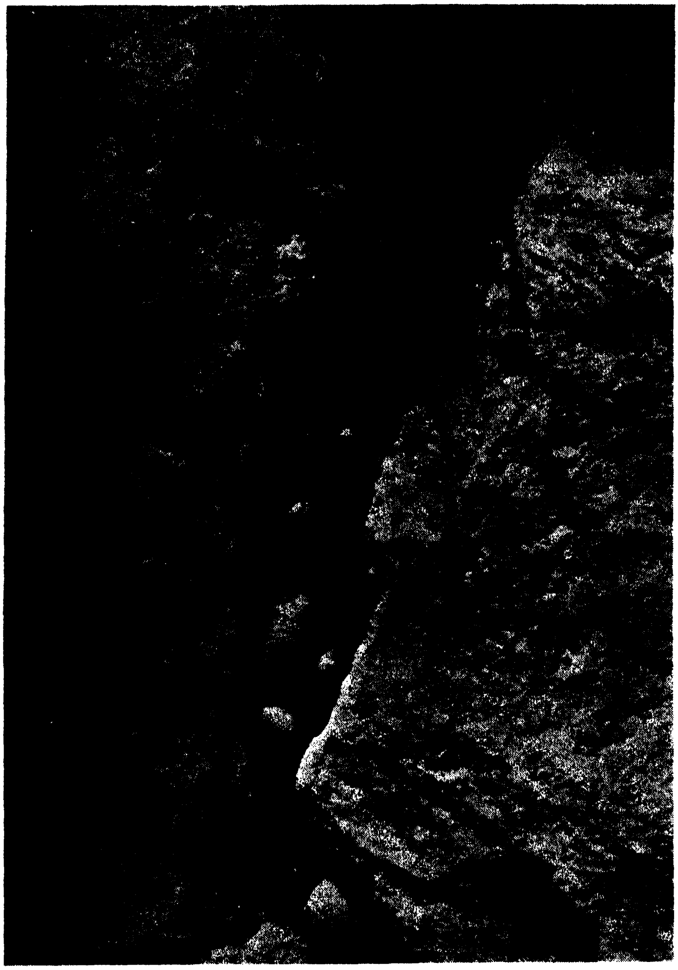
Butterflies are at their best when the sun is warming the earth. Bright light and warmth are essential to them. They are positively heliotropic and thermotropic.

Biologists have detected tropistic responses as consequences of a number of different stimuli. Light (phototropism or phototaxis, heliotropism or heliotaxis) and gravity (geotropism or geotaxis) are well known. There are also hydrotropism, a turning towards water; hygrotropism, a choice of a moist atmosphere; chemotropism, a turning towards certain compounds; stereotropism or thigmotropism, an inclination to bring the body into contact with solid surfaces; rheotropism, a tendency to keep visual images on the same spot in the retina; thermotropism, a seeking of warmth; vibrotropism, a response to vibrations; anemotropism, an orientation to the wind; and galvanotropism, a turning towards anode or cathode. These turnings, tendencies, inclinations and so on are in general shown by invertebrates, and most of the experimental work has made use of such animals as hydroids, insects, worms and molluscs, while spiders illustrate several tropisms very well



The spider *(Folcus phalangoides)* seeks a corner of the room, preferably under the ceiling or under a shelf. Because it goes upwards away from the floor it is said to be negatively geotropic: that is, it moves away from the earth. And because it prefers to have its body in contact with solid surfaces, it is referredto as positively stereotropic.

The Cecropia Moth on an iris. Most moths rest during the day, preferably hidden in a shaded place, and in this they show a strong contrast to the butterflies. Moths are, as a consequence, said to be negatively heliotropic.



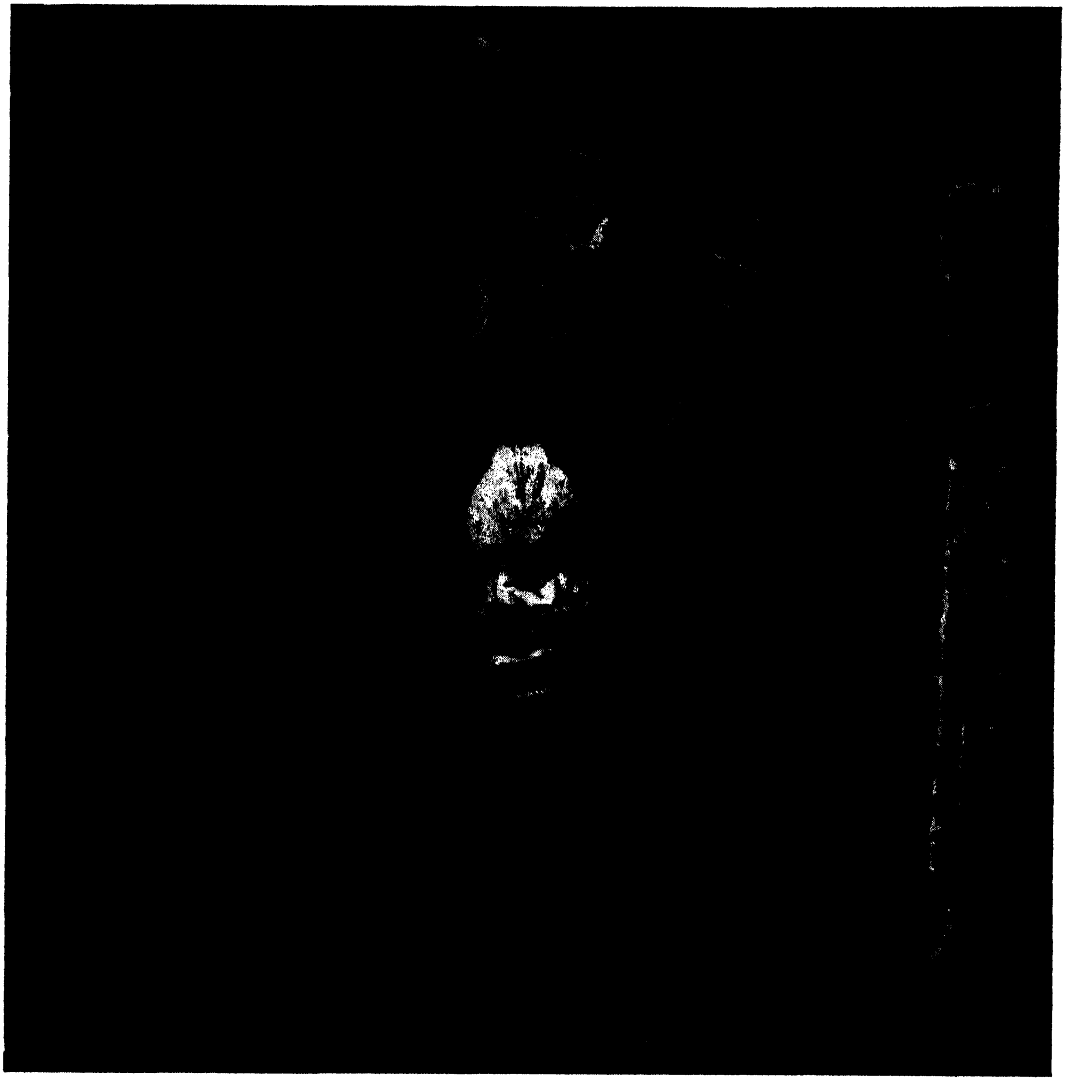
Snails hide up in dry weather, or seek shelter in moist places, coming out for full activity after rain or heavy dew. They are said to be positively hygrotropic.

Most spiders appear to shun the light and seek the dark, that is they are negatively phototropic. The mechanism of this must be the reverse of that described for the photopositive moth: light shining in the eyes on one side of the spider results in an extension of the femoral muscles so that the spider runs in a curved path with the concavity on the darker side. A spider's stereotropism or tendency to secrete itself in a crevice, from which its web diverges, acts in conjunction with this, since crevices are usually dark. When such spiders are put into an ordinary square box they come to rest in the corners. If they are given a cage with a dark crevice and a light one, they will enter the dark crevice, showing that they are photonegative, but if there is an illuminated crevice only they will enter it in preference to staying outside, showing that their stereotropism is stronger than their negative phototropism.

Again, many web spiders show negative geotropism and climb upwards before spinning their webs. The various spiders which may be found on window-frames in sheds and cellars will often be seen on examination to have mounted to the top of the pane and to have chosen as their resting place a corner with a solid surface above them. If such spiders are put into an experimental circular cage with a crevice leading out of the circle, they invariably enter the crevice if it is pointing upwards, but they will never go down into it if the cage is turned round. Thus they show that their geotropism is stronger than their stereotropism.

Hygrotropism, either positive or negative, is strongly developed in many kinds of spiders. Those that spin webs in shrubs and bushes can usually be shown in experimental cages to rest in a moister atmosphere, while those that spin on walls and fences will rest in drier air. Rheotropism is also well shown and is easily demonstrated with wolf spiders running in the fields. If the hand is moved over the spider from behind it turns about and runs in the opposite direction. A German biologist some years ago, working on wolf-spiders and jumping-spiders, was able to distinguish the muscular response which followed the falling of images on each eye in turn, an admirable example of the so-called "forced movements" which are the basis of tropisms. Spiders are animals in whose lives vibrotropism plays a great part, since vibrations of their webs guide them to their captives. Photography has clearly shown how the waiting spider turns itself so that the vibrations of its web equally stimulate the legs of both sides. There are some spiders which live near water and rest with their forelegs on its surface. An insect alighting on the surface sets up ripples, which guide the spider as it runs out to secure it. Both web-spiders and ripple-spiders can be made to run out to a vibrating tuning-fork which gently touches their webs or the water.

Anemotropism is usually shown by insects which fly with equalised pressures on their wings. It is interesting to note the same kind of orientation in young spiders which, having climbed to a suitable height before starting on their gossamer-flights, turn their heads towards the wind. This turning is directed solely by the wind. Galvanotropism is of less significance, since electric

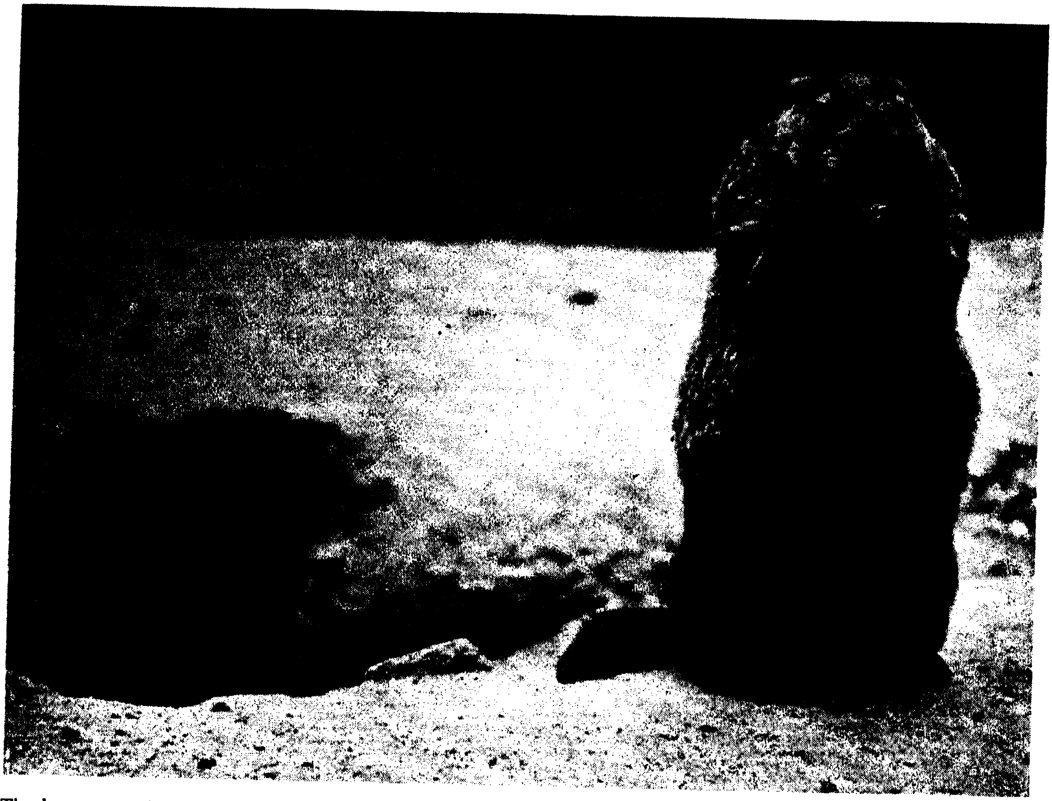


Having spun its web the spider retires to a corner but holds a thread in its foot. A fly landing on the web struggles to get free and the spider, feeling the vibrations in the silk threads, comes out to deal with its prey. It is responding to a vibrotropism.

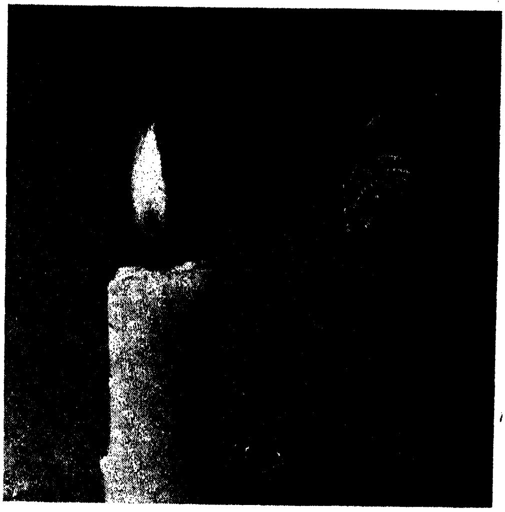
currents do not frequently occur in nature. In general the effect is to extend the limbs on the side of the cathode and flex those on the side of the anode. If a current is passed through an aquarium containing a water-spider, it turns and swims towards the anode.

Experimental work on tropisms should aim at establishing a relation between the behaviour of the animals and the laws of physics and chemistry. This is not always easy, but it can sometimes be done. For example, an electric lamp may cause half of a group of hydroids to bend towards the light in ten minutes. If the distance between the animals and the lamp is doubled the intensity of illumination falls to a quarter of its former value, and it will be expected that 40 minutes will pass before half the hydroids have turned as before. The calculated times can be compared with the observed times in a series of experiments with different distances. If the agreement is close, the mechanical nature of the animals' response is demonstrated.

Secondly, an attempt should be made to measure one tropism against another. For example, a certain flatworm which will swim away from a lamp and towards a cathode is placed in a dish with an electrode at each end and a lamp at one side. When there is no light, the worm swims towards the cathode, when there is no current it swims away from the light. By varying the strength of the current and the brightness of the lamp it is found that the animal swims at an angle of 45° to both stimuli when the current-density is proportional to the logarithm of the intensity of illumination. A mathematical relationship of this kind is desirable in any experi-



The larger animals respond to changes in conditions in the same way as the lower animals, but because their reactions are more complicated we seldom speak of them as tropisms. The woodchuck, or ground-hog, of North America hibernates, and is said to take its first peep at the weather on February 2nd. According to the story, it will go back into hibernation for another six weeks if it sees its own shadow. Presumably this is because a warm February means a late cold spring.



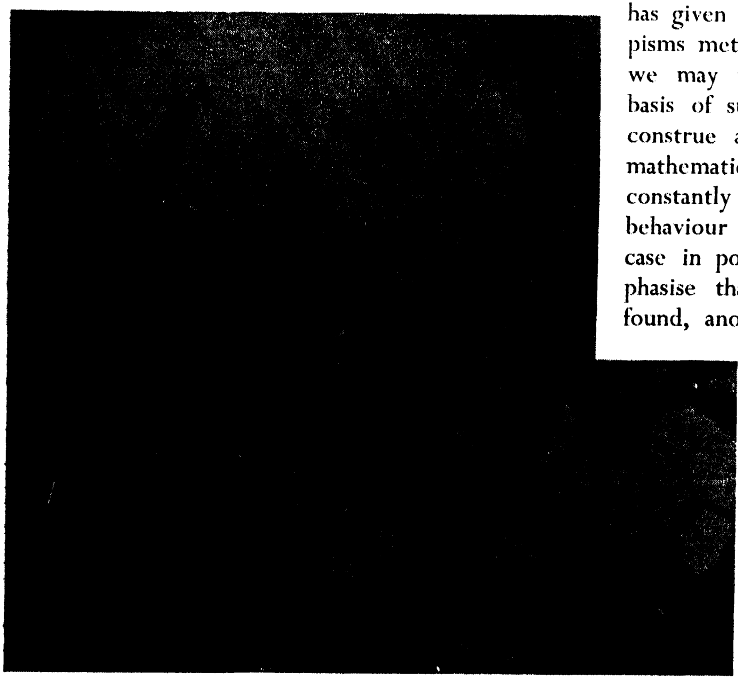
A posed photograph of a moth flying round a candle flame. The primary reason for the moth's behaviour is tropistic, but many other influences come into play to vary this behaviour. Even in so simple an action as this, behaviour may be seen as a many-sided thing.

ments on tropisms; and it is from such results that the tropistic theory has arisen.

The contrast between purely mechanistic behaviour and the purposeful behaviour of a man is well illustrated by considering the responses to a doubled stimulus, such as two lamps. A man wandering at night across the country and seeing lights in two cottages, directs his steps towards one of them: a photopositive animal would be compelled to pass between them at an angle depending on their relative brightnesses.

Mechanistic biologists have not been able to secure universal acceptance for the theory that all animal behaviour is that of a tropistic machine, and it may therefore be asked: What is the place of tropisms in the life of the animal? The answer seems to be that tropisms are the directed reflexes which orientate an animal in its varying surroundings, determine the direction in which it moves, and so play a large part in bringing it into an environment to which it is adapted and in which it can survive.

In the preceding pages, Mr. Theodore Savory has given a general outline of the tropisms met with in animals, and how we may interpret behaviour on the basis of such tropisms. If we seek to construe animal behaviour by strict mathematical rules, however, we shall constantly meet with anomalies. The behaviour of a moth to a light is a case in point. And in order to emphasise that such anomalies will be found, another point of view is presented below.



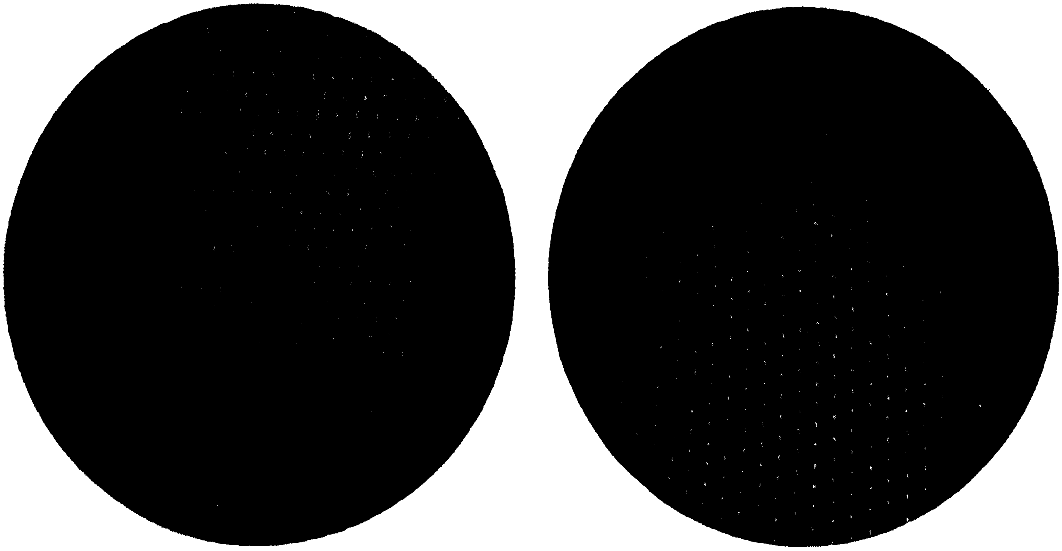
Example of a reflex. The female Mantis is eating the body of a male. Ten hours after the head was bitten off the dead insect was still moving its legs and when touched lifted its wings as though still alive.

THE SACRED FLAME AND ITS DEVOTEES

The behaviour of moths in the presence of a light appears to be specially arranged to refute any theory put forward to explain it, and in this connection an event which took place in the small hours of the morning may be recalled. The window was slightly open, and a lighted candle was on a table placed immediately beneath the window. The night being fine it was not long before the outer surface of the window-pane was covered with small moths, some of which found entrance at the top of the window.

Some twenty or so were all that gained admittance at first, the others appearing to move as if distractedly seeking the way in but not finding it, and these twenty took up positions around the candlestick at various points on the table. Without exception, they had taken up a position with their heads towards the light. In a very short time, one of them took wing, circled round the flame, singed its wing, and fell through the flame, a burning mass, into the molten wax beneath. This tragedy enacted, another followed. And so, at irregular intervals, they tried, one by one, their luck around the flame. Some perished in the flame itself; some dropped into the molten wax at the base of the wick; others escaped with singed wings only and retired to the surface of the table, with wings more or less useless. Some were content to remain on the table and worship the flame from afar, making no attempt during the whole hour or more to approach it. Some of them seemed to be even less attracted, and spent their time wandering aimlessly about the ceiling and walls. By far the most curious thing was the sight of several of them, with wings too charred for use, crawling slowly and deliberately, often painfully it seemed, up the candle and walking straight into the base of the flame. A more deliberate *hara-kiri* can hardly be imagined. It

On the left, the full-grown caterpillar of the Cynthia Moth (*Attacus cynthia*) is about to spin its cocoon in a leaf, having first attached the petiole to the stem by wrapping it in tough silk and fastening the end of the silk to the stem. Within the leaf on the right, the pupa of the Cynthia Moth rests secure even though all the other leaves on the tree may fall.



On the left, part of the many-faceted cornea of the multiple eye of an insect. On the right, a candle flame photographed through it. This probably shows the effect of a candle flame on the eyes of a moth.

was interesting, too, to see that, while the majority circled round the flame in decreasing circles, many flew straight into the flame.

No one theory seems to account for the diversity of behaviour shown. There is, for example, the familiar view that to a moth a bright light is as irresistible as is daylight to a growing plant. Yet some of these moths, although facing the light all the time, refused to be drawn by it. There is also the theory that once at close range, the moth cannot help flying in decreasing circles around it. Yet some of these moths flew round the flame, and some straight into it. These, and other theories, probably explain a part of the truth, but the most attractive is that put forward some years ago by a French scientist, that the attraction is due to a nascent or feebly-developed artistic sense, and that the reaction of any individual moth would be determined by the degree to which this sense was developed. In pursuance of this argument, he instanced the case of human beings and illuminated signs. If we analyse the reactions of a crowd to illuminated advertisements, we find that some people regard them as horribly inartistic and a blot on the landscape, some are mildly amused, and others intensely thrilled. Some will pass them with unseeing eyes, others will give them but a tolerant, disinterested glance, while others will stand and gaze, to a greater or lesser extent, awe-struck.

The scientist adds piquancy to his theory by calling attention to an even closer similarity between these two things than appears on the surface. He reminds us that an insect's eye is composed of a number of facets, and that in all probability the image of the flame is registered separately in each facet. In other words, that, what to our eyes is a single point of light, to the moth is a dazzling display of hundreds of tiny lights. And that this brilliance will fascinate the more artistic moths to the point of painful suicide.

The account given above of the erratic behaviour of the moths around the candle flame does not prove that the experimental work on tropisms, and the conclusions arrived at as a consequence, is incorrect. On the contrary. But it does draw our attention to the ever-present possibility of a particular sequence of behaviour being due to a number of variable factors.

EGG POPULATIONS AND PARENTAL CARE

It has long been a matter of common observation that some animals produce large quantities of eggs or young each year and others produce only a few. Yet very few investigators have attempted to make critical observations, or to compile statistical data, upon which exact conclusions could be based, though recently Gunnar Thorson of Sweden has attempted to review the problem in regard to marine animals. In the meantime, however, there are a few broad generalisations that can be made.

The first generalisation is that the number of young (or eggs) produced each year decreases, on the whole, as we pass upwards in the animal scale. This is, of course, correlated with the greater tendency towards increased parental care. To contrast two extreme cases, it may be pointed out that an oyster merely casts its 500,000,000 eggs into the sea to take their chance against enormous hazards so that eventually only one or two will survive to the adult stage. On the other hand, an elephant which gives birth to one (or at most two) young will nurture it, tend it and protect it. In this way, speaking generally, the populations of each species, oyster or elephant, throughout the world will not vary significantly from one year to another, whether the adults produce 500,000,000 or one offspring each year.

The next generalisation is that the number of young produced each year tends to be fewer the greater the size of the animal. Again we may refer to the 500,000,000 to 1 ratio as between the oyster and the elephant. On the other hand, there are so many exceptions to this that even as a generalisation the statement errs on the side of over-simplication. As we shall see later, parental care correlated with small size of brood is often found in animals of small size and also in some of the smaller lower animals.

The third, and probably the most significant, generalisation is that reduced fecundity, coupled with some degree of parental care, is found in some species of all the main phyla of animals. In other words, that this phenemenon of reproduction has been evolved independently again and again. A single example will perhaps give point to this. There are, living in inshore waters of the coasts of Europe, three species of *Littorina*, marine gastropod molluscs, the largest of which, *L. littorea*, is known as the winkle. This species, and the other two, *L. obtusata* and *L. saxatilis*, though differing in size, colour and other details, are nevertheless closely related. Moreover, they occupy a similar habitat and generally speaking live under very much the same conditions. In breeding habits, however, they differ considerably. *L. littorea* lays some 10,000 eggs a year, *L. obtusata* lays one to two thousand (the number not being so accurately known) and *L. saxatilis* lays 100 to 400 a year. *L. littorea* lays its eggs in tough, horny capsules, and the larvae on hatching are pelagic, forming part of that teeming microfauna which with the microscopic plants constitute the bulk of the plankton, upon which so many of the larger marine animals (crustacea, fish, etc.) feed. *L. obtusata*, on the other hand, lays its eggs in gelatinous masses attached to seaweeds, and the larvae are non-pelagic, remaining near the bottom. Finally, *L. saxatilis* is viviparous (see page 216) and the young are born in the crawling stage. The hazards attendant upon the pelagic larvae of *L. littorea* are very much greater than those for the non-pelagic larvae of *L. obtusata*, while the larvae of *L. saxatilis*, by the very nature of the advanced stage at which they are born, have the greatest chance of survival. Side by side with this, the young of *L. littorea* are counted in tens of thousands, those of *L. obtusata* in thousands, and those of *L. saxatilis* in hundreds. Nevertheless, at a later stage in their life-histories, when the offspring of all three species have reached a comparable form—that of young crawling gastropod molluscst—heir numbers will be roughly the same.

See also the table on page 41.

CHAPTER V

THE BACKGROUND OF LIFE

THE ANIMAL AND ITS SURROUNDINGS

THE mural paintings and carvings on bone in the caves of prehistoric man leave little doubt that he had a very close and intimate knowledge of animals. His interest would be practical in the first place; these were the animals he hunted for food. The drawings show, however, that his interest embraced an aesthetic approach. In addition, the natural history knowledge of prehistoric man included doubtless what we should now call folk-lore, that is incomplete knowledge in which superstition and the romantic story fill the gaps. This tripartite character of man's attitude to the world of living things persisted until the full flood of Western civilization and the growth of towns and industry caused so large a part of the population to lose interest in all but artificial things. As the interest waned, however, another thing occurred. The more educated people began to take a renewed interest: they found in nature a relief from the more material things; it became a thing of beauty and a source of knowledge. At the same time began the building of private collections which later fostered the growth of museums.

It is of interest to recall that primitive peoples to-day still have a high degree of natural history knowledge. They know where to look for this plant or that animal, and their knowledge is sufficiently wide to enable them to understand cause and effect in disease, to see the connexion between climatic changes and scarcity. The Masai of Central Africa, for example, have known for centuries that malaria was caused by the bite of a mosquito, a thing that civilized man had to re-discover by long and patient research.

With Darwin's generation came a new interest in natural history, in the quiet, patient observation of natural phenomena and the accumulation and elucidation of information. This era was succeeded by one in which the laboratory ousted the field as a means of research, but of recent years there has been a swing back, in the course of which the field observation, the classifying of animals and experimental work in the laboratory are being combined. It is now realised that the animal must be related to its natural surroundings, and a special branch of biological science has been established for this, known as Ecology.

THE ANALYSIS OF ANIMAL COMMUNITIES

The ecologist studies the relations between animals and their surroundings. He finds that it is not possible to interpret the life or behaviour of any species without a full appreciation of the soil, the vegetation, the climate, as well as the other animals living with it, on it or in it. That is to say he seeks to relate an animal to its habitat and to the community of which it forms part, and he finds that there is a fair degree of constancy in the different kinds of animals found in a particular habitat and also a well-defined structure in the organisation of the community itself. This is no more than should be expected but is more than we ordinarily suspect. We should not expect to find woodpeckers where there are no trees, even though they may occasionally feed on the ground; or crossbills where there are no pines, since they feed exclusively on pine seeds. But the dependence of a species upon a particular habitat is not always as obvious as this.

The animal communities may be further subdivided. For example, every community has its herbivorous animals and its carnivores, and the

Grunts *(Brachygenys chrysargyreus)* from Florida rest under the large Gorgonids by day, coming to the surface at night to feed.
(Courtesy of U.S. Fish and Wildlife Service.)

A flight of gulls. Most birds are active during the day and roost at night.

Whether nocturnal, diurnal or crepuscular, practically all animals must rest at some time. Here the photographer has surprised a fox, which is active mainly at night, asleep during the day.

latter can be subdivided again into the predatory animals and the parasites, although parasites, too, can be herbivores, as, for example, plant-lice. Further, both herbivores and carnivores can be either nocturnal or diurnal, so in any community there are those species active by night, and those active by day, with the borderline cases, known as crepuscular, such as certain bats whose activity is confined to the period of twilight.

In the sea, there is the same orderly arrangement into communities. This may be readily seen on the shore between tide-marks and has formed the subject of many interesting researches. In addition, many marine animals are affected by a tidal rhythm.

The orderly arrangement of the communities, whether woodland, heath, desert, swamp, seashore or deep sea, is maintained by the simple process of each animal, pair of animals or group, occupying what has been called a niche, that is a disposition in which the individuals of each species do not come into dangerous competition with each other. The occupation of a niche may be passive or active: passive as where a marine animal once established will inhibit the settlement of another which requires the same food; active, and more obvious, as when birds, and others, lay claim to a territory and dispute it violently with any intruders.

The construction of a community will also depend fundamentally on food-chains. The soil will support a certain plant on which a particular insect feeds, the spider feeding on the insect itself forming the food of an insectivor-

Diurnal and nocturnal animals. One half of the world does not know how the other half lives. This is true of animals no less than human beings. Some animals are diurnal; that is they are most active by day. Others are nocturnal, most active at night. The butterfly moves about by day and rests at night. The moth, on the other hand, comes out as the butterfly goes in. Some animals are most active at twilight, and are said to be crepuscular.

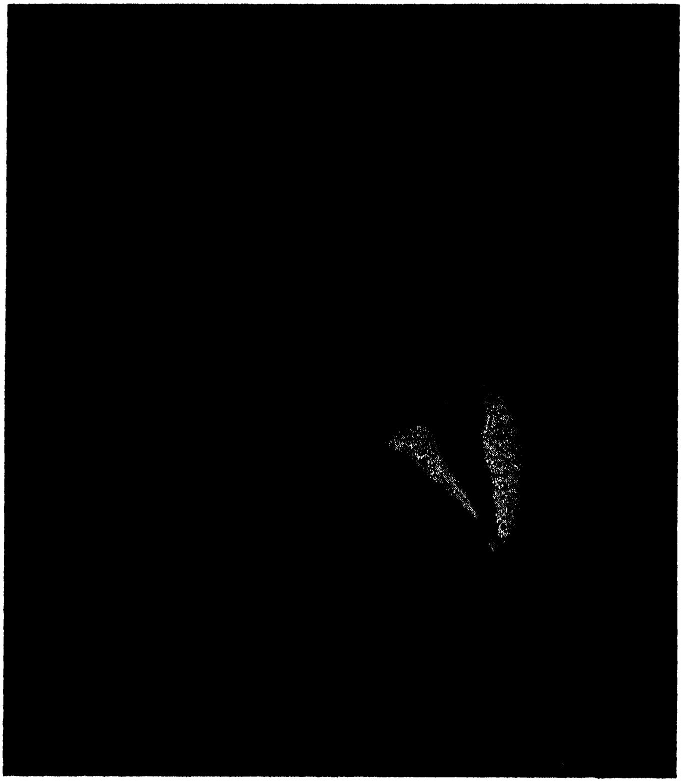
ous bird, in turn the prey of a raptorial bird. In the sea the microplankton, plants and animals, support the copepods on which the giant whales feed. These food chains are usually short, and lead logically to the idea of a pyramid of members. That is, the numbers of individuals decrease, but their size increases, as we ascend from one stage to another in a given food chain.

Most of the animals in a community are likely to lead isolated lives, or at most associate in pairs, but many form social communities, for example, rookeries, heronries, and so on. There is an obvious advantage in this for purposes of protection, but the interdependence has been carried further than this to the point where in certain species a psychological interdependence appears, the members of the community being unable to breed if the numbers fall below a certain minimum. Finally there is the community of complex organisation, including slave and guest species, a civilisation not unlike that evolved by man.

THE STRUCTURE OF HABITATS

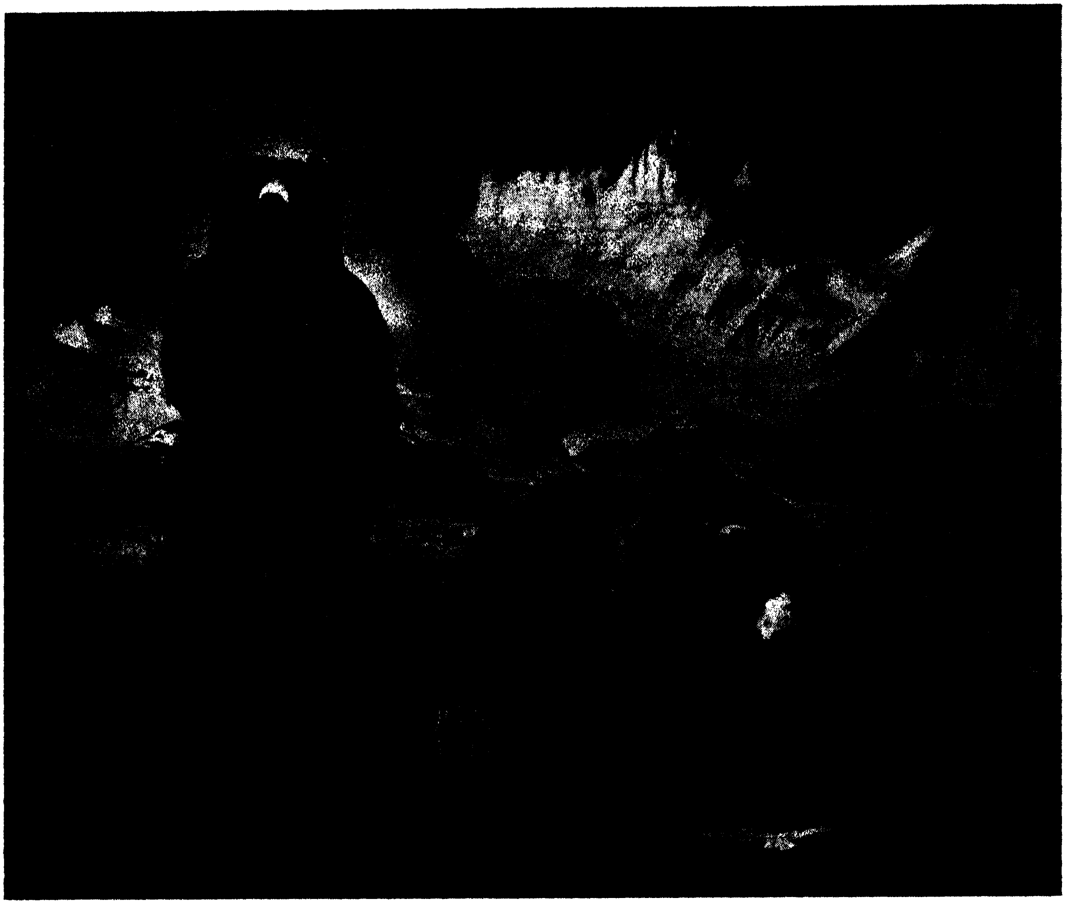
About a century ago, it was sufficient to speak of the habitat of an animal in very loose terms. To

A Mouse-eared Bat resting during the day. Many bats are crepuscular.



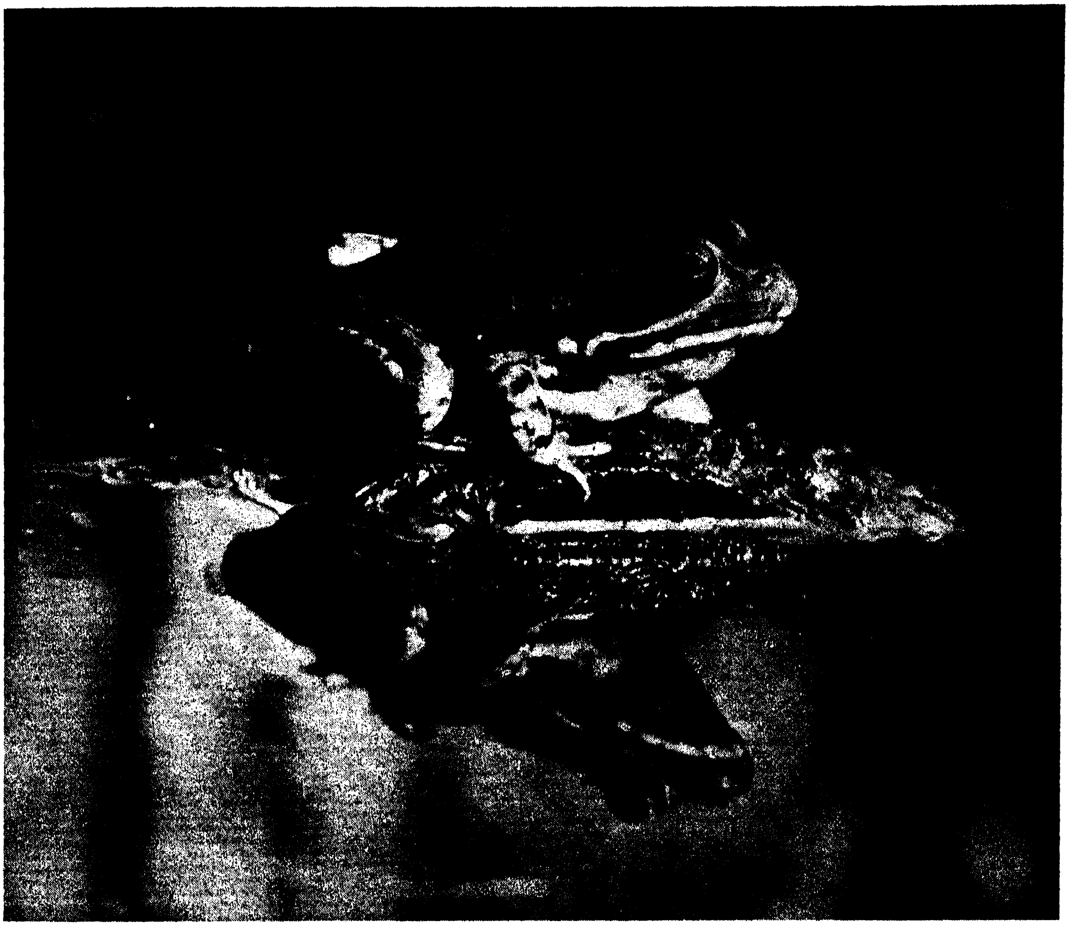
Although possessed of powerful limbs and claws, badgers are mainly inoffensive. It is probably for this reason that their habits are nocturnal.

say, for example, that a particular animal was found in pine-woods, or on a rocky shore, was considered enough to satisfy all needs. But just as Natural History has developed into the science of Ecology, in which more precise observation is made of all things affecting the life of an animal, so the word habitat has come to have a more precise and infinitely more detailed connotation; indeed, it is often difficult to draw the distinction between it and the more familiar word environment. Habitat, in its modern sense, has come to include not only the physical factors, the kinds of rocks and soil, together with the vegetation, but also the other animals, together with those further physical features which make up climate, such as humidity, temperature, light-intensity and so on. Moreover, it is realised that no habitat is static, that it changes from day to day, even from hour to hour, and that many of the changes are of supreme importance in the life of the individual animal. If environment has any meaning apart from habitat, it must include not only the changing effects of the behaviour of other animals and plants on the individual under study, but also the behaviour of the physico-chemical elements. This point is returned to on p. 105.



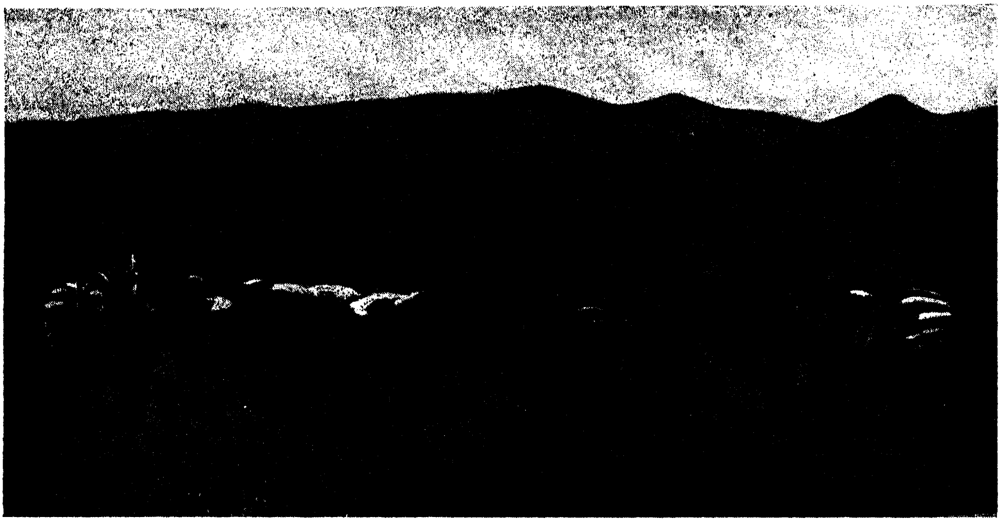
The importance of the habitat is emphasized by the increasing tendency in museums to exhibit animals in their natural surroundings. This picture shows a habitat group, in the American Museum of Natural History, of the Alaskan Brown Bear.

Not only is habitat the complex of vegetable, animal and physical factors in which an animal finds itself, not only is that habitat constantly changing, but the particular species whose habitat we seek to study contributes to its own habitat, for questions of population density, and other things more subtle, affect the species for good or ill. So Ecology, or the study of animals and their surroundings, has led us into chemical analysis of the soil, the freshwater or the sea, meteorological records, the taking of periodic censuses, and a vast mass of statistical work without which the individual observations would be valueless. The layman may well be forgiven for asking if all this detailed work is necessary. The answer is simple. On the results of such work depends the solution to many problems of food-supply and health, by the conservation of the world's resources of food, or by the combating of disease. Indeed, although natural history or ecology may have had its origin in a pure desire to know, the stress of economic circumstances has forced the pace and demanded more and more information. We may, perhaps, go further and say that on the accumulation of such detailed knowledge may depend the ultimate fate of the human race.



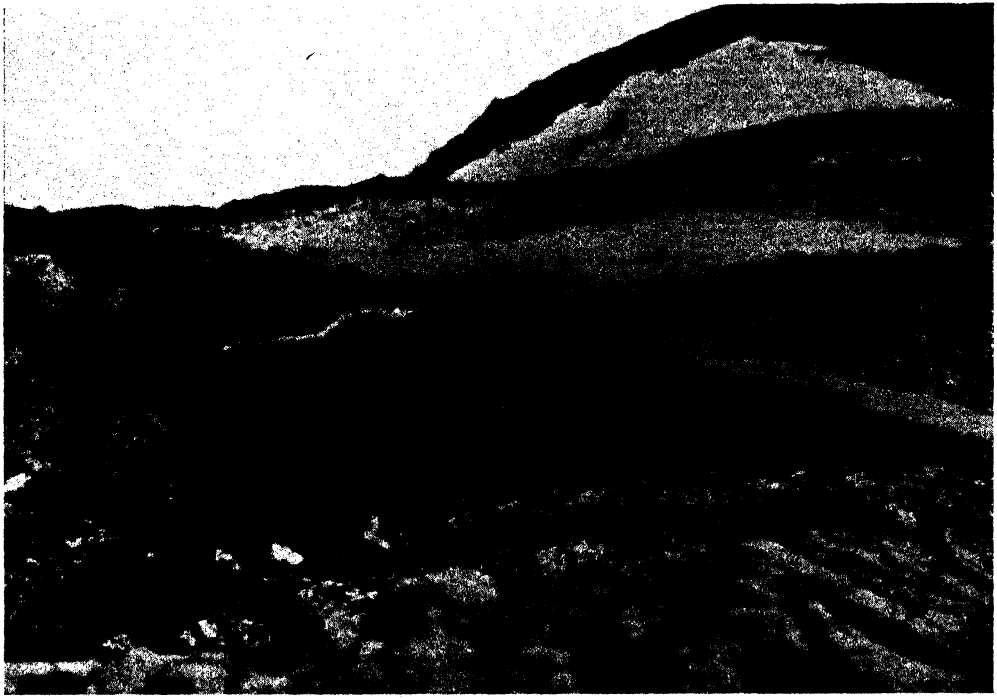
The Bullfrog, like all Amphibia, can live in water and on land, but if out of the water a moist situation is essential. Its habitat, aquatic or semi-aquatic, is determined by the great need of keeping the skin moist.

Here, then, perhaps a word might be spoken in favour of pure science, which works slowly and carefully, having generations ahead in view, as compared with applied or economic science, through which, because quick results are often demanded, faulty conclusions are often arrived at and untold harm done by the urge to deal with a problem of the moment. Moreover, it may be confidently said that if any considerable

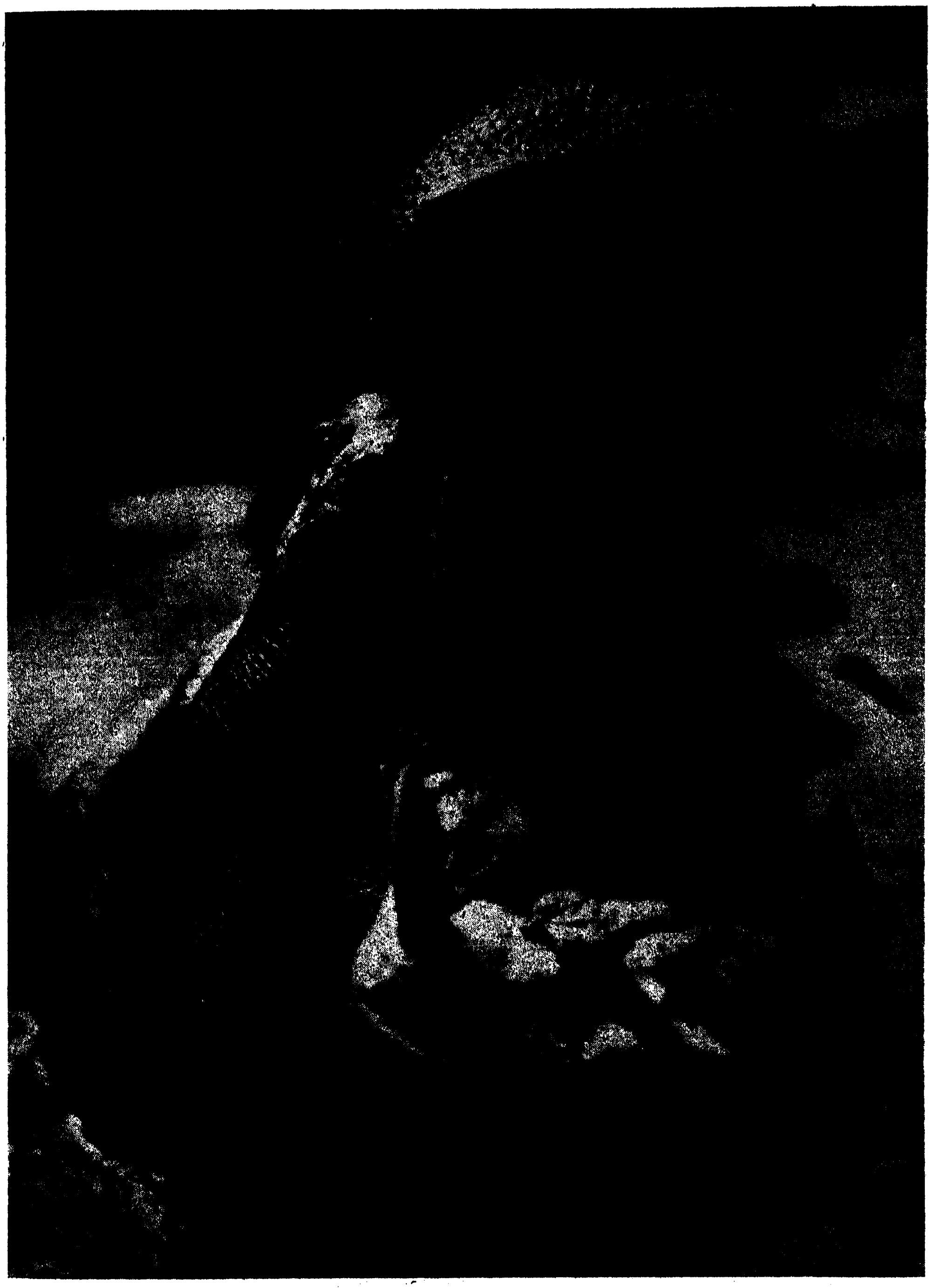


The zebra and the wildebeest will be found only on grassy plains.

progress is to be made in ecological research the amateur naturalist must be called upon a great deal more than in the past. At the same time, there is a contribution all can make, by an understanding that the lives of animals are interwoven into a complex which must be unravelled

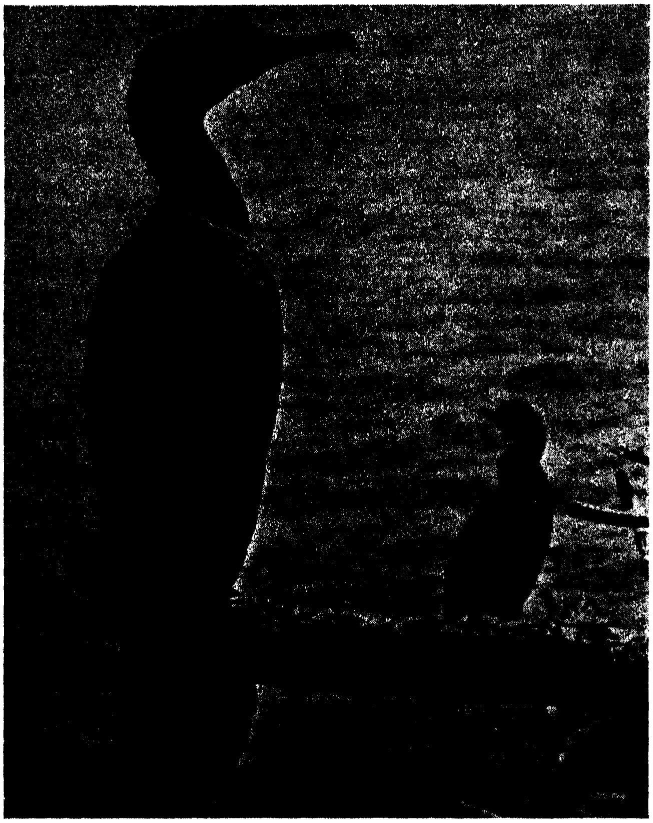


Musk Ox, a hoofed mammal related to the bison, is a massive animal with black hair covering the body. It lives in the rough regions of Greenland and Arctic Canada and is adapted to a cold, dry habitat.



The Hippopotamus must have swampy rivers.

The huge weight of the hippopotamus is largely borne not by the short pillar-like legs but by the mud and water in the tropical swamp in which it lives. Its food, the luxuriant vegetation, is near at hand. Most of its time is spent in water, but when at night it forages on land it chooses muddy runways leading into the swamps.



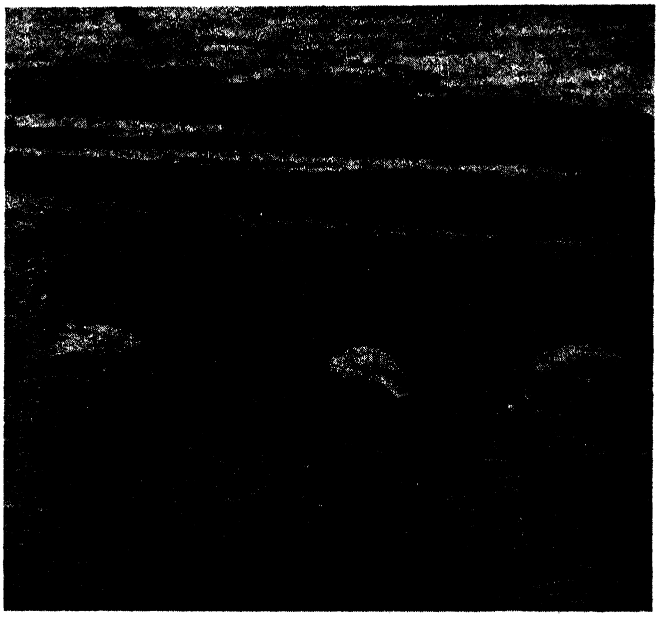
The habitats of some animals are clearly defined. We should not expect, for example, to find cormorants where there are no fish.

before we can understand fully, and accurately, even one or a few aspects of them. In other words, that a problem in biology, whether it be how to conserve the herring harvest, prevent the recurrence of plagues of insects, or stop the spread of disease, cannot be solved without detailed research by many people over a long period.

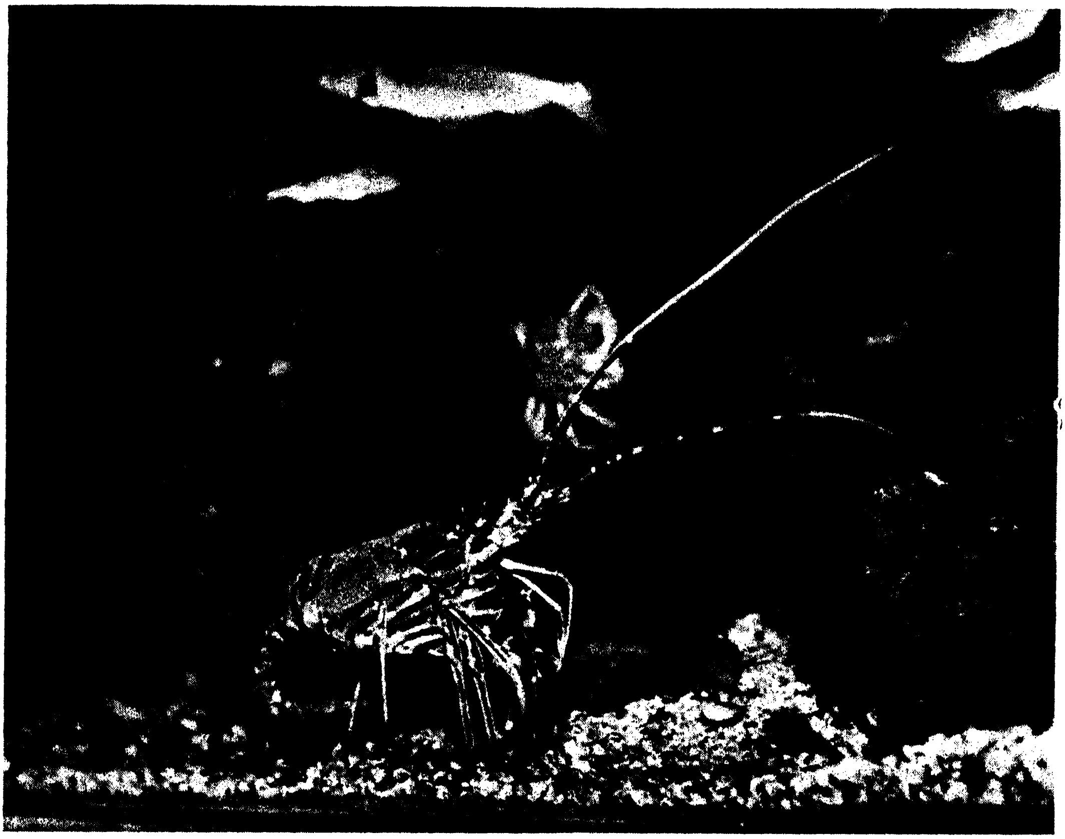
Having stressed the value of studying habitat we may now proceed to consider what such study involves. It is, of course, obvious that within so small a space it is not possible to do more than hint at the tremendous issues involved. Some idea is given of numbers in animal populations throughout the world on page 250 and if this is linked with the thought that any habitat is subject to variations in vegetation, animal populations and climatic conditions, and that within the broad variations there are minor fluctuations, then at least the mind is rendered receptive to further learning. If also we can appreciate how interlinked each feature of the habitat is with all the rest a valuable lesson will have been learnt.

THE DELICACY AND STABILITY OF NATURAL BALANCE

An animal's interest in plants is twofold, as food and as shelter.



Spoonbills will be found only in the region of muddy lakes, because they can only feed by spooning watery mud and eating the small animals living in the mud.



The Crawfish or Rock Lobster must have a rocky habitat into the crevices of which it can retire for safety.

A plant, on the other hand, requires the materials resulting from the animal's excrcrement, and from the decay of its body. There is here a complete cycle. Again, a change in the vegetation will result in a change in the animals occupying the habitat of which that vegetation is part. At the same time changes in the animal population will affect the plant communities, as when an animal feeding on a particular plant or seed becomes rare in a given habitat, the plant flourishes more than heretofore, possible choking out other plants. Here then is another cycle; and the more we examine the structure of communities, the more we see cycles within cycles, resulting in a balance of extreme delicacy.

Perhaps the most remarkable feature common to communities, ecological groups, individual animsls snd plants, even to natural solutions like sea-water, is that while there is constant change, variation and fluctuation, there is nevertheless an underlying stability, an inherent resistance to permanent change, which defies exact analysis. For example, the hydrogen-ion concentration in sea-water is about 7, and this can be altered by the addition of an acid or an alkali, but within a matter of hours the normal equilibrium will have been resumed. In plant and animal communities there is a similar stability as the study of populations has indicated, although the time required for the equilibrium to be regained is measured in years.

For every species of living thing there are optimum conditions for the maximum length of life, activity, reproduction and population increase. Under such conditions, the welfare of the species is at its highest. Above or below the optimum conditions the general well-being of the species community or group will decrease. This fact is of considerable importance in such things as the control of pests and the conservation of food supplies. So the study of population numbers is assuming a new importance as the numbers of the human race increase while the sources of food decrease, due to overfishing and over-hunting, and the denuding or de-vitalizing of huge areas of the land proceeds apace.

THE STUDY OF ANIMAL POPULATIONS

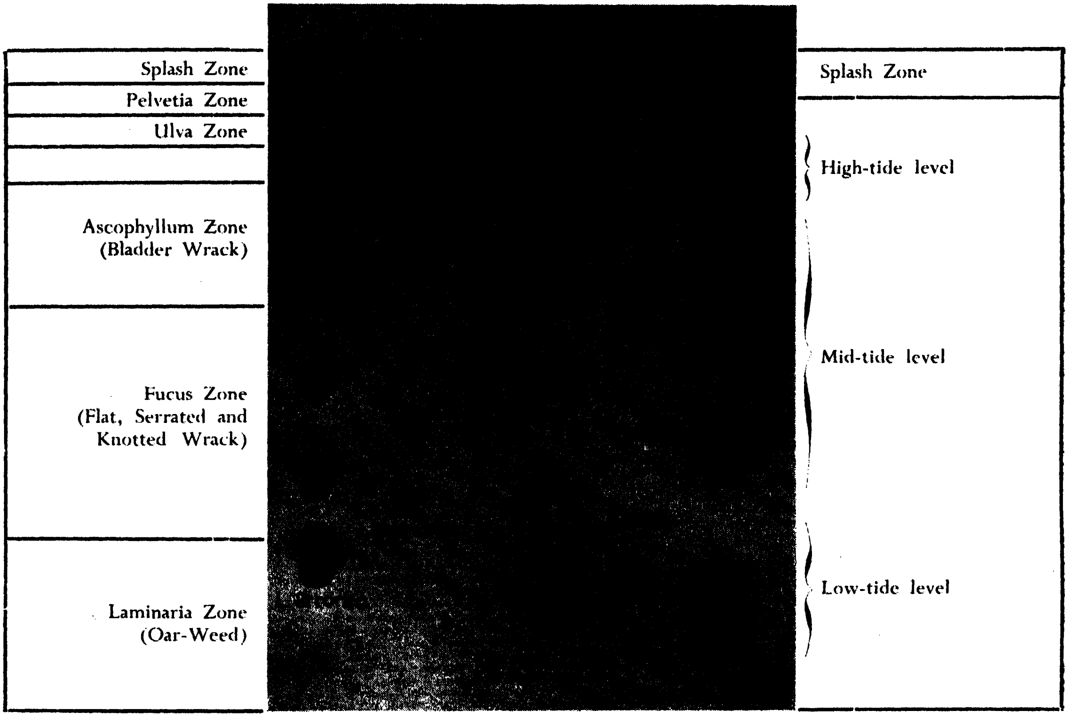
The study of numbers in regard to populations may be divided into the statistical, the study of the numbers of various animals, the limits to their increase and their local aggregations at a given moment, and the dynamical, or the rates of increase, fluctuations in numbers and the effect of environment over a period of time. These studies, laborious to the workers carrying them out, usually too detailed and complex for any but the specialist to comprehend, have an immense significance in the study of evolutionary processes, as well as a practical value to generations yet to come.

One feature of unusual interest which has emerged from this study is that not only by exceeding the optimum conditions will overcrowding occur, but by reducing them undercrowding will result, and both are harmful to the community concerned. The overcrowding in a community of mammals, for example, usually results in an outbreak of disease, the overcrowding itself apparently having produced optimum conditions for the spread of the disease. Undercrowding usually has a deleterious result because of its effect on reproduction. For example, to reduce it to absurd proportions, a male and a female mouse being the only representatives of their species in a square mile of territory probably would not meet and therefore would not mate. This example is not so absurd as it appears, for animals are not capable of such wide roamings as we are apt to believe but tend to be very conservative in habit, confining their wanderings to a restricted territory. Reductions in numbers have therefore a cumulative effect, by causing reduction in breeding. On the other hand, an upset in the balance of male and female will also have a similar effect, especially if there is an abundance of males to worry the females causing thereby a disturbance in the breeding rhythm. Finally, even in gregarious species it is believed that the reduction in numbers of a community below a certain point

Although they fish as individuals, cormorants like to sit on the rocks in groups, and they nest in communities.

will cause a failure in the emotional stimulus to mating.

Enough has been said to show that the balance in nature is all important; it is a thing difficult to upset yet so finely adjusted as to be dependent often on factors almost undetectable. On the other hand, it is a subject the importance of which we are only now becoming aware. The produced substances which promote their own growth, it does suggest that materials may be produced which have an advantage, which we cannot even guess at yet, to members of their own species. At the other end of the animal scale we have the interchange of saliva between a pair of doves billing and cooing without which nesting and incubation fail to take place.


Splash Zone
Pelvetia Zone
Ulva Zone
Ascophyllum Zone (Bladder Wrack)
Fucus Zone (Flat, Serrated and Knotted Wrack)
Laminaria Zone (Oar-Weed)
Splash Zone
High-tide level
Mid-tide level
Low-tide level

Perhaps one of the clearest examples of the relation of animals to their habitat is seen on the shore between high- and low-tide marks. This diagram shows how certain species of mollusca, on the shores of the British Isles, are distributed in relation to the seaweeds and to the movements of the tides. For example, most of them increase in size as the low-tide mark is approached, because there is the longest period for feeding. But *Tellina tenuis* is largest near high-tide mark, where only a few individuals are found.

question has been posed: Do animals produce their own growth-promoting substances? To this there is no decided answer, only a few indicators that the answer may be in the affirmative. It has been observed that young barnacles will settle best where other barnacles have already become established, and it is believed that this may be because of some substance given off by those barnacles that have successfully settled. Although this example does not point directly to the barnacles having

THE FAR-REACHING EFFECTS OF TRACE ELEMENTS

In any consideration of an animal's surroundings, whether we call it environment or habitat, we cannot at the present stage of our knowledge omit reference to that group of substances best referred to under the generic title of trace elements. To introduce the subject it may be as well to recall that in the early days of food analysis the chemists found they could estimate the numbers of calories, proteins and so on, and in addition there were a number of elements in such small quantities, usually of the order of one part in a million. These small traces were regarded as of no value and were ignored. We now know that trace elements are often vital to the health, if not the existence, of an animal. For example, the presence of cobalt in clover in the proportion of one part in a million will keep sheep free of rot. Copper, in the proportion of one part in seven thousand million is necessary for the successful settling of oyster spat. There can be little doubt that over and above the more obvious things that govern the lives of animals there must be many such trace elements, or minute traces of other things, which we as yet do not suspect.

The eyes of a night hunter: the Eagle Owl *(Bubo bubo)* of Northern Europe.

Probably the two most important aspects of present-day biological research are concerned with balance and trace elements. And man's ignorance in both fields is likely to cause the human race considerable loss if more attention is not paid in the near future to them. The list of man's interference with the balance of nature is a formidable one, and is still growing, and his interference with natural environments is already having wide repercussions, the effects of which are not necessarily apparent yet. They include such obvious things as intensive agriculture, coupled with the increased use of mechanical transport and the loss of natural manures, a loss we seek to make good by the use of the less satisfactory artificial manures. Oil pollution at sea and the chemical pollution of rivers is another obvious example. Then there are the numerous examples of whole species which have been exterminated or nearly so. The passenger pigeon of North America is the classic example of extermination by man, although there are others, and for partial extermination we need only recall the Greenland Right Whale, the bison and others. But perhaps the biggest upset to the balance is in the animals transported by man from their natural habitat, the rabbit to Australia, starlings to North America, the Colorado beetle to Europe and a considerable number of other insect pests.

It is always as well to remember that the removal of an animal from its habitat means the loss of a link in a well-balanced chain, the effects of which are none the less far-reaching even though they may not yet have been computed.

HABITAT AND ENVIRONMENT

Before leaving this subject it may be as well to make clear the distinction between habitat and environment, two words which are apt to be used loosely or even as alternatives. The one is positional and the other qualitative. Or, in other words, the habitat is the locality in which an organism grows and develops, and the environment includes all those things influencing its growth and development. For example, two species of sea-anemones, having the sea-shore as their habitat, may, if they are growing several miles apart, have totally different environments, such as differences in temperature of the water, salinity, oxygen content of the water, in the amount of food present, polluting substances and large number of others.

THE AFRICAN FRONT

by

DR. GEORGE CRILE*)

In the civilized part of the world the soil, the plants, and the animals are so completely under the domination of man that one can scarcely see the play of the great natural forces, free from the modifications made by man.

In the First World War I attempted an interpretation of men at war in France – rich, beautiful France, for ages modified by a brilliant, industrious, artistic people, a land of terraced vineyards and trained trees, a land of metaled highways and model villages, a land where the cycle of fertilizing, sowing, reaping, and fertilizing again keeps a part of the surface of the earth in ceaseless rotation.

It was from this territory, at an intensely human stage, that I viewed the Great War. On this land masses of French, German, English, Italian, American, Australian, New Zealand, East Indian, Canadian, and Portuguese troops were crowded in dense concentration. On this land was also the greatest massing of human mechanisms ever seen. There were mules, horses, dogs, and pigeons, bred and trained by man. There were such nonliving mechanisms of energy as motor cars, tanks and tractors, airplanes and balloons, shells and bullets, bombs and mines, firebrands and poison gas; there were bayonets and trench mortars, radio and telegraph, Red Cross nurses, surgeons, priests, prayers, and oaths.

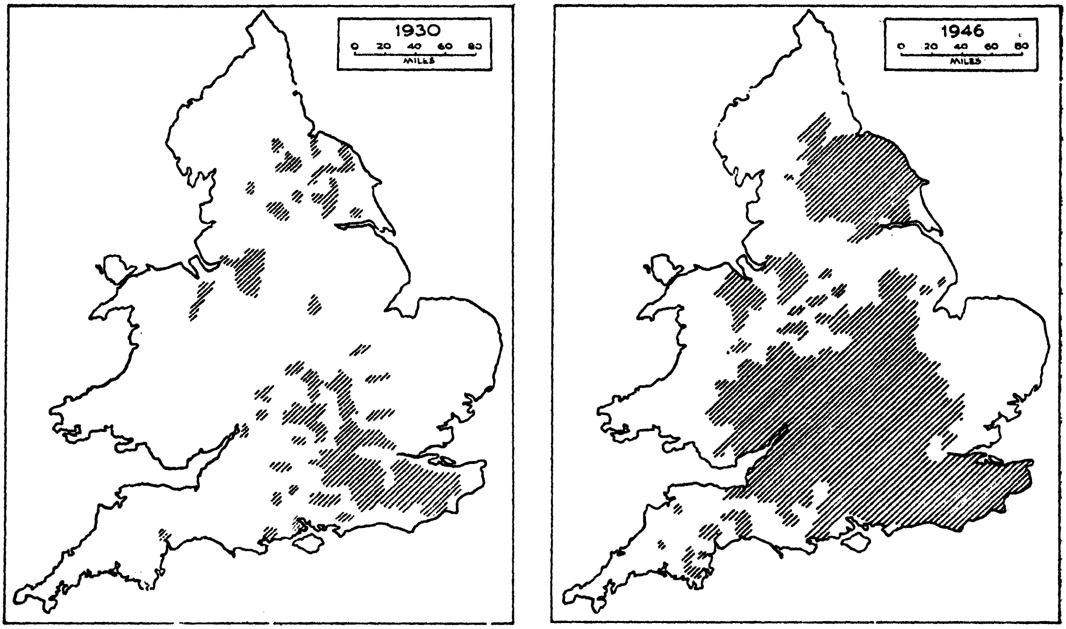
In our expeditions to equatorial Africa I visited a front that civilized man has not dominated; a front in many respects as intensive as the French front of the First World War, though devoid of civilized elements; a front that derived its driving energy from the equatorial sun and some of its rich soil energy from one of the greatest events in geologic time, namely, the formation of the great rift between Africa and Asia.

In the First World War the struggle among rival nations was for dominance. On the African Front the struggle is for food and against a natural prey. On the French Front there were no women and children. On the African Front young are born and raised, and each member of the family spends his life struggle on the front.

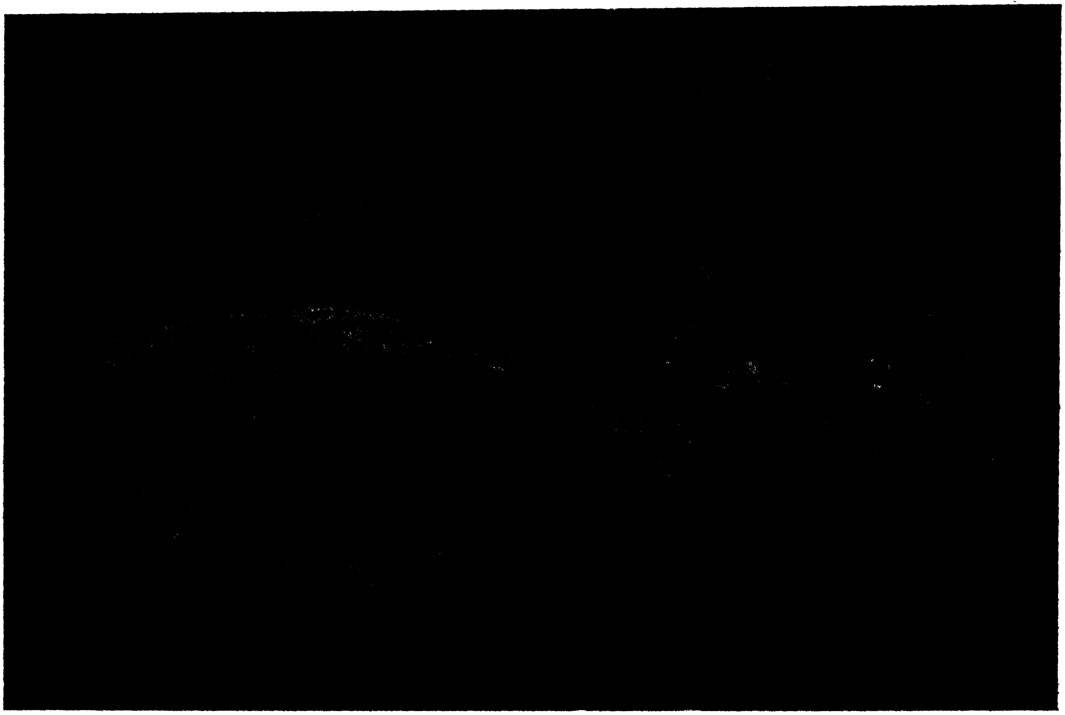
On the French front a casual observer could see

---

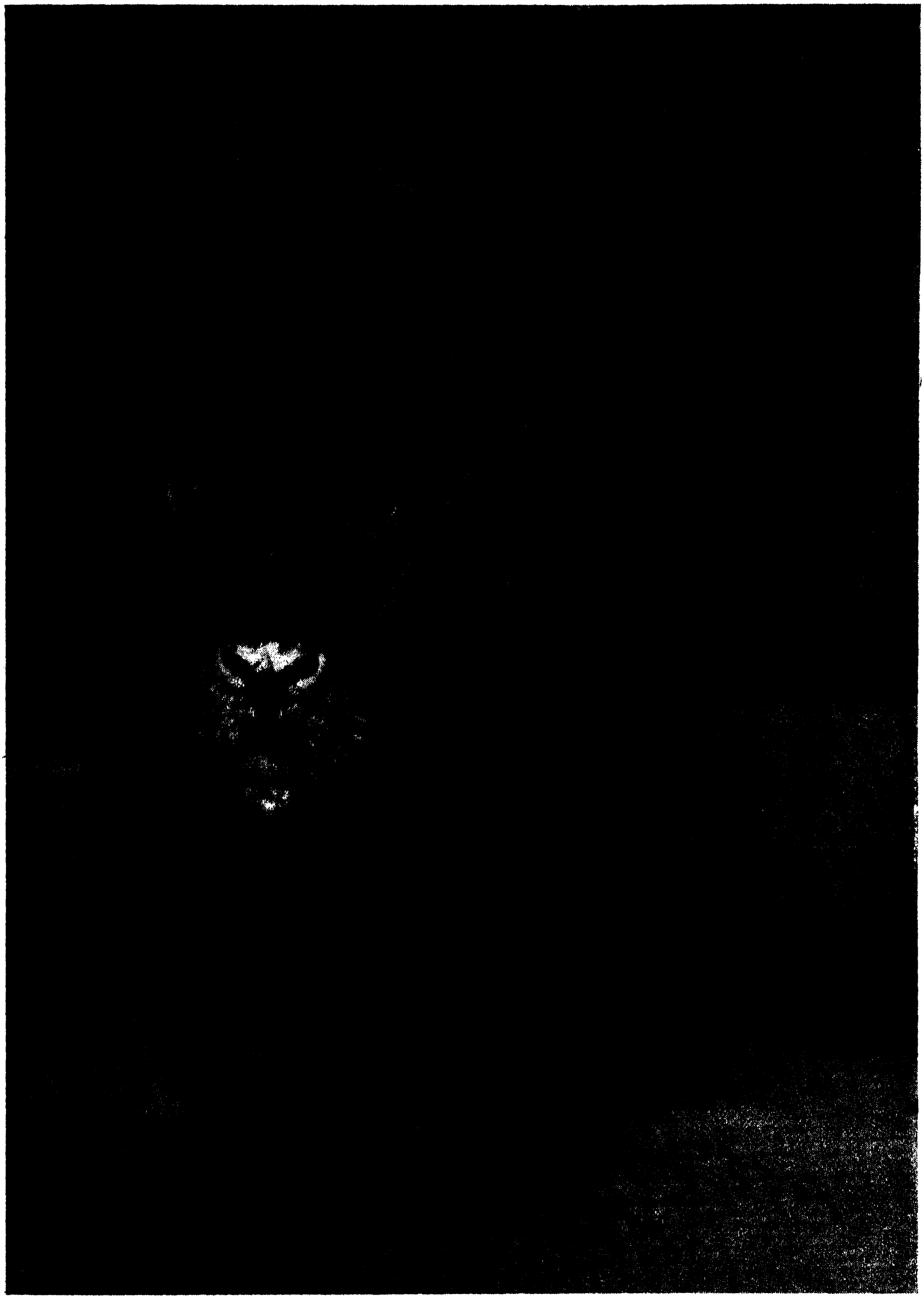
*) From Dr. George Crile, Intelligence, Power and Personality. (1941, Whittlesey House, McGraw-Hill Book Compagny, Inc., New York)



Maps showing the distribution of the Grey Squirrel in England in 1930 and 1946.



A young Grey Squirrel learning to scramble along a branch. The Grey Squirrel, introduced into Britain from North America, has found a home without natural enemies, and a favourable environment. Consequently, it has spread rapidly and is becoming a pest. It has been the subject of a widespread census from which valuable information has resulted.

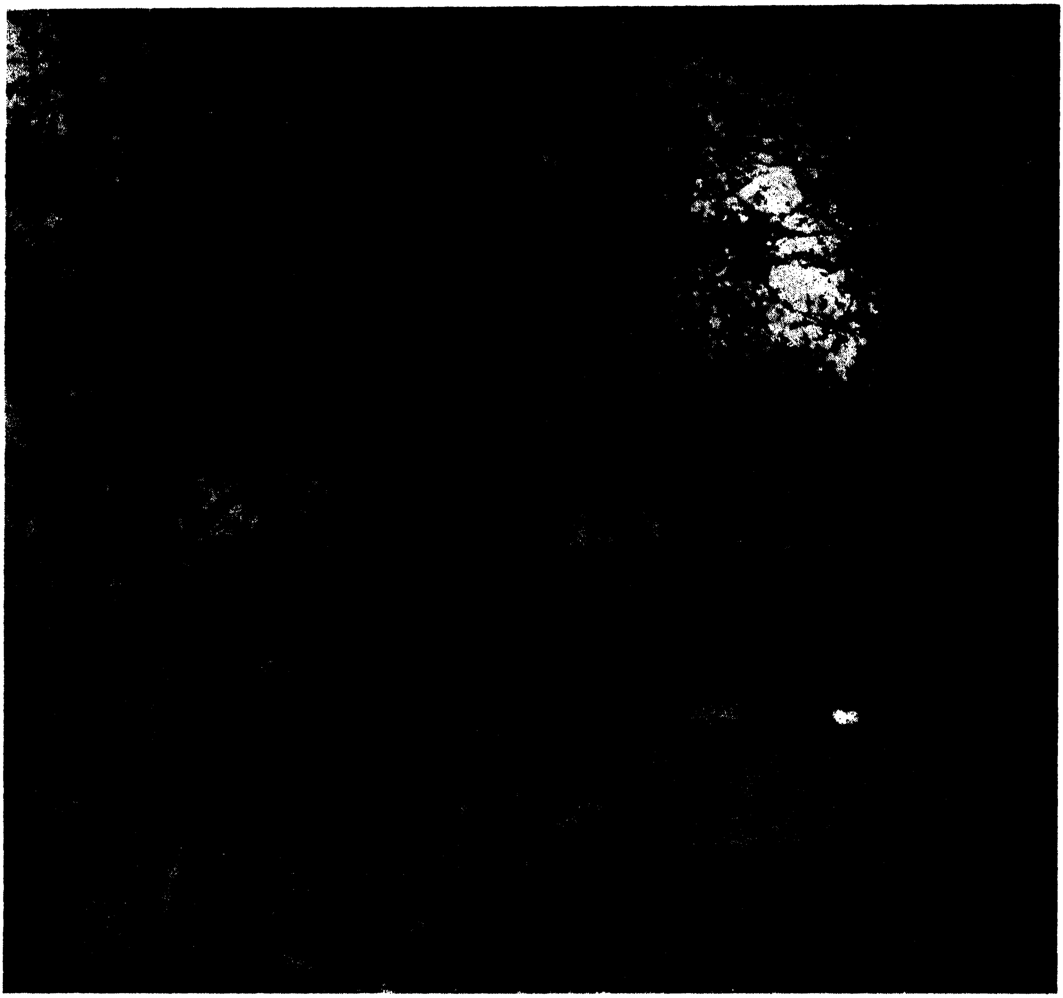


The sinister appearance of the black panther typifies the relentless prowling hunter.

nothing – no gun, no soldier. The nearer the fighting front the more peaceful and quiet it seemed when no 'kill' was on. It is likewise with the African front. The African front is in every blade of grass. It is in the water and in the air. It is behind every sheltering tree or rock. It is in the burrows, in the deepest jungle, and on the open plain.

In France the front existed for several years, only. The African front began when life began. As many soldiers populated the French front as animals the African front. On the French front raids were common. On the African front no night passes without raids. In war camouflage is utilized. In Africa animals are born camouflaged.

In Africa each day the native kills many animals with poison arrow, spear, or trap, and each day a number of natives are killed by poison fangs, teeth, or claws. Each day, also, lions, leopards, cheetahs, civet cats, jackals, ostriches, secretary birds, and the greater and lesser bustards kill thousands of mammals, birds, snakes, and scorpions. Birds kill thousands of insects, and insects, in turn, kill myriads of birds and animals; and the countless billions of living things reveal-

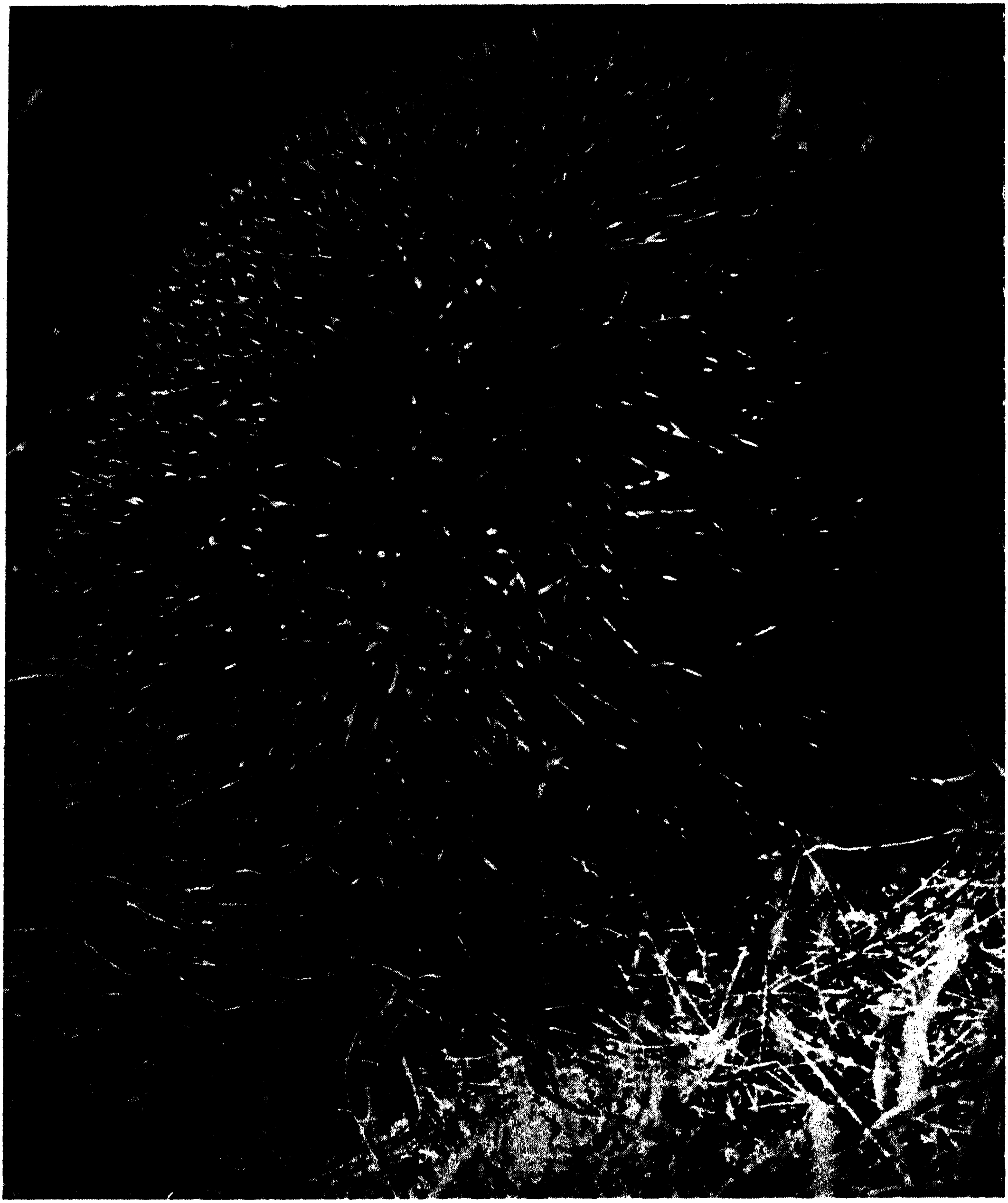


The terror that walks by night. Lions, like cats, do most of their hunting at night, stalking their prey through the undergrowth and seizing it in one tremendous leap.

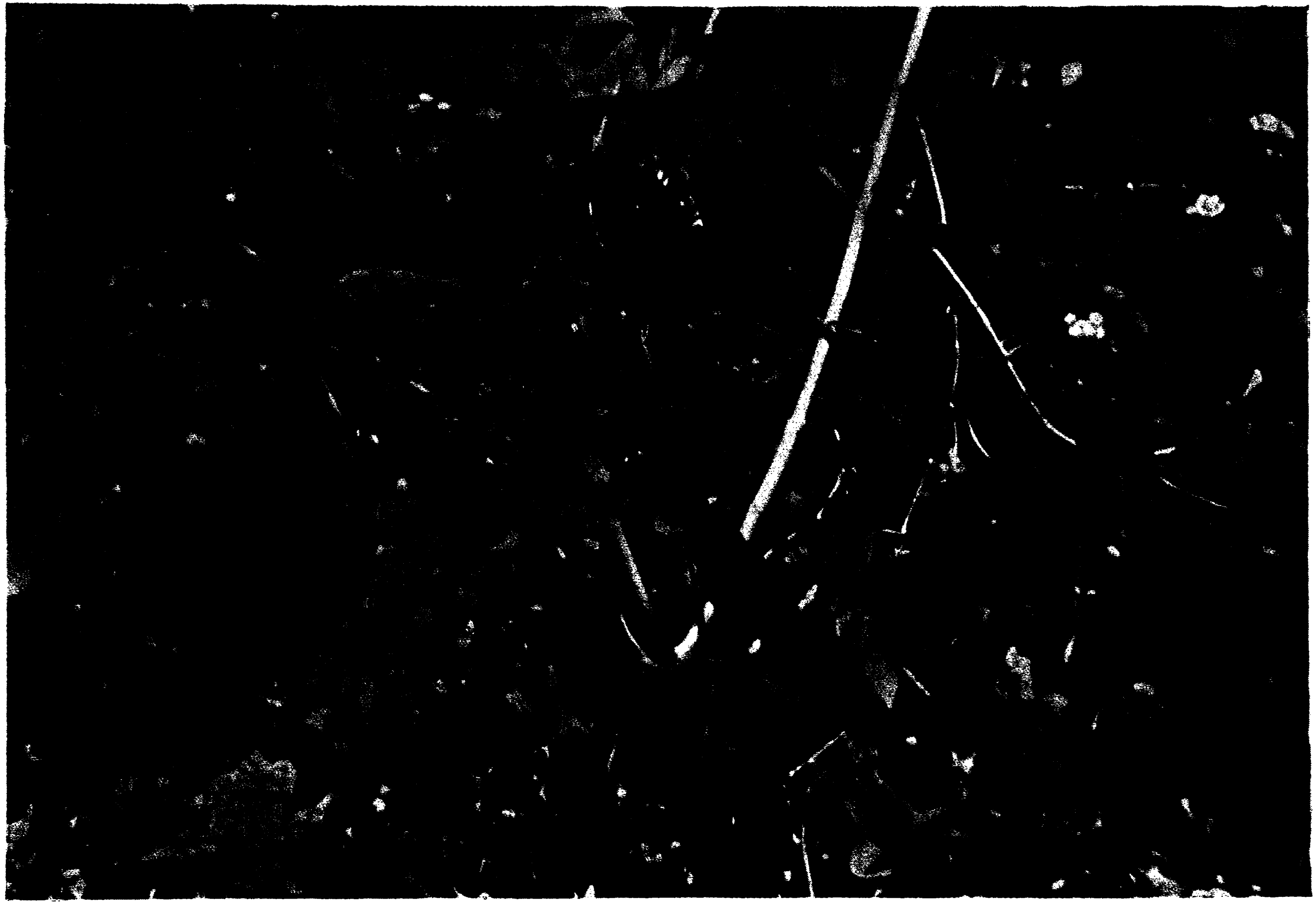
In the darkness of the night there is a rustle of leaves and a loud squeak. A Screech Owl has just captured a mouse, which hangs limp from his beak.

ed only by the microscope—the greater world of bacteria—take the largest toll.

Not only is the animal world in constant struggle in Africa, but, on an even wider front, plant warfare is extended. Many animals attack plants, and plants, in turn, defend themselves against the animals by thorns, by poison, by bitter acrid taste, by climbing heights, by delving into swamps, and by forming jungles. Just as the most relentless warfare of animal



Few animals can boast so good a protection as the Hedgehog. Only the most resolute dog, a hunger-desperate fox or the hardy badger will dare to attack.



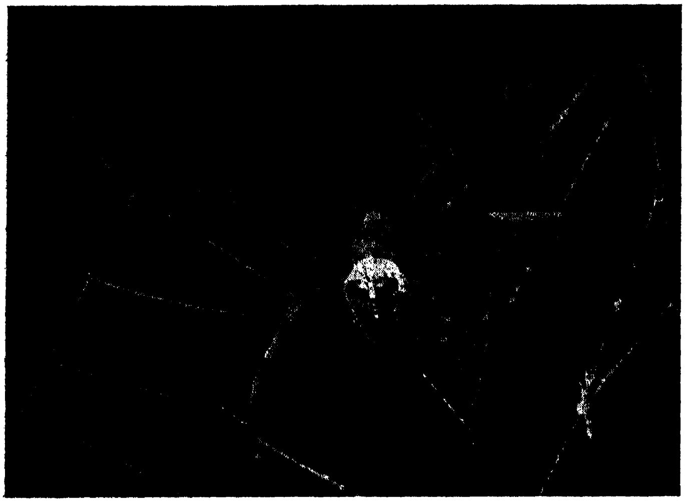
A chameleon in its natural habitat, among the foliage where with its long, extensible tongue it catches insects.

The fight in the underworld: Praying Mantis captures a butterfly. The struggle is not confined to the large animals but exists as a ceaseless strife among all forms of life.

After the kill. A falcon has captured a hare and is about to eat it. An important difference between the struggle between animals and man-made war is that animals normally kill only to feed.

The struggle between animals is not always so obvious. Here is a lobster on which mussels have settled and grown to full size, hampering its movements and finally killing it by a slow process of attrition.

A Praying Mantis with a wasp gripped in its powerful fore-legs.



A silken snare. A spider busily overpowering a bee caught in its web.

plant. A plant fights for sunshine, for moisture, and for soil, and to this bitter struggle plants draw many animals. The nectar of flowers entices the insect to fertilize distant plants and trees. To exact payment for the fruit, which bears energy to the animals, trees subsidize animals to spread their kind by carrying their seeds.

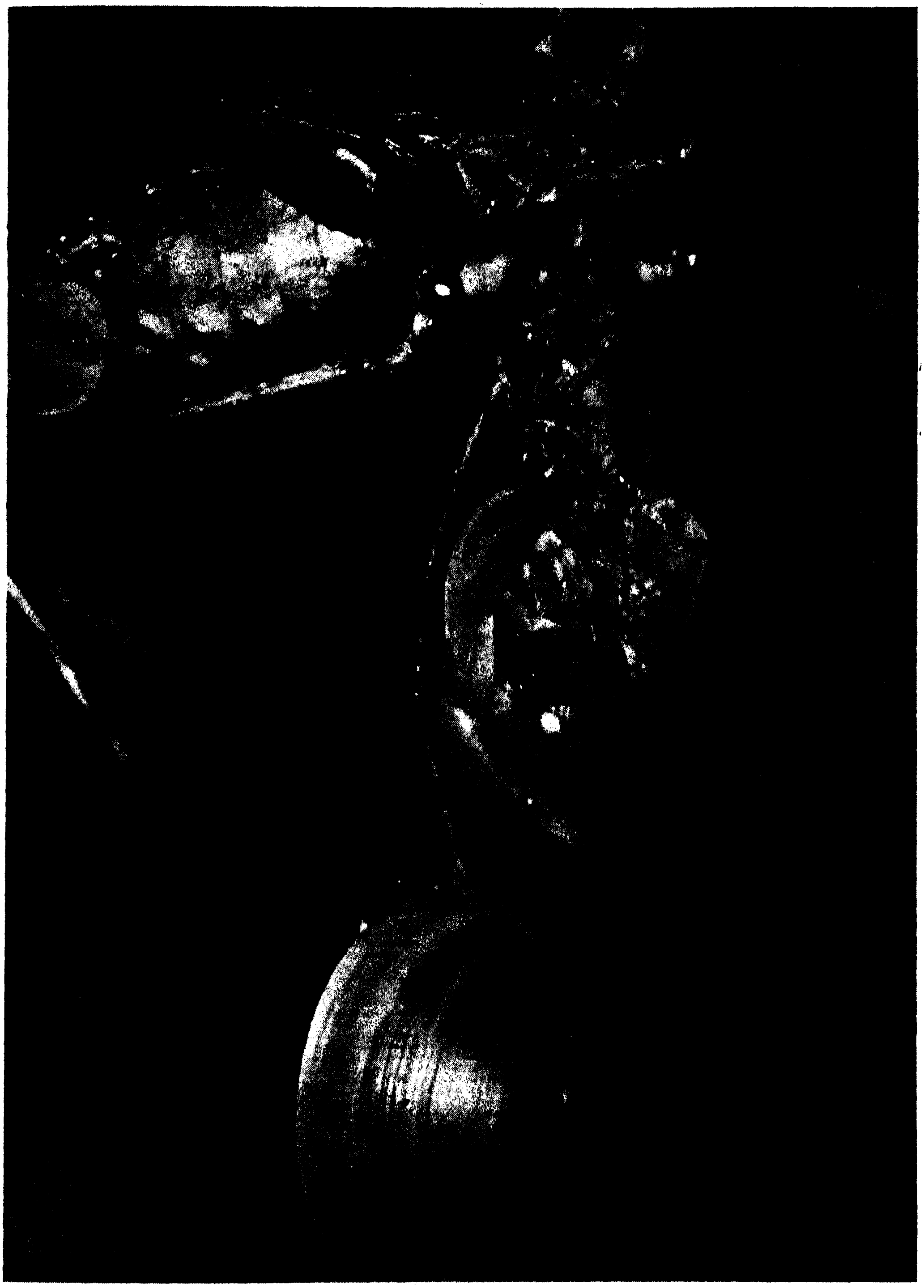
Thus the plant sustains and kills the animal; the animal sustains and kills the plant; billions of plants and animals are killed, and millions are born every day in this age-long struggle; in fact, a day on the African front is

against animal, and just as man's warfare against man is the most bitter, so in the plant world the most relentless warfare is that of plant against a day of countless deaths, countless births, countless conflicts, countless victories, and countless defeats.

ANIMALS KNOWN FROM SINGLE SPECIMENS

Of the million or so recorded species of animals, there are many that are known by a single specimen only, but as one scientific expedition after another returns, as our knowledge of the living world expands, such species are correspondingly reduced in numbers. And this applies more particularly to animals living on land, and especially to the larger animals. Yet we have a fair idea that, in such places as the dense unexplored forests of South America, there live birds and mammals which, from what we know of them at the moment, must be classed as rare. There must be many more which have not yet been seen by naturalists. It is, however, in the sea more than on land that "rare" animals have been, and still are, being obtained; just one specimen only known, like *Latimeria* (see page 128). Occasionally a large fish is caught, and in its stomach is a smaller fish the like of which has not been seen before. Or it may be that the belly of a large whale, cut open on the flensing deck, yields a new species of animal. From this and other evidence we are sure that there remains much yet to be discovered, especially in the depths and the wide expanses of the oceans.

The discovery of new or rare animals offers one of the more fascinating sides to the study of natural history; and it is not in the deep seas alone that they are to be found. Exploration of caves and underground streams is constantly bringing to light small creatures of unusual form and strange history. Water pumped from deep wells and filtered will often provide an interesting catch. But if we are content with small things, insects, spiders and the like, there is no need to search the inaccessible places; we may quite easily find new forms on our doorstep.



Nemesis has overtaken the dragonfly nymph. The insect was found in a pond struggling to free itself from two freshwater mussels that had closed tight on its feet.

FOOD CHAINS

The interdependence of plants and animals is intricate and subtle, and can be likened to a vast system of rachet-wheels working one on the other. This is, however, an over-simplification of a very complicated and detailed process, often described as the Balance of Nature. A few of the more straightforward examples are given below. These are based on materials in *The Ecology of Animals*, by Elton (Methuen), 1933.

1

Lapland buntings
feed on spiders

Hunting spiders
feed on spring tails

Spring tails (insects)
feed on plants

Plant living in
the soil

Soil fertilized with
humus from dead plants
and animals

2

Sparrowhawks feed
on woodpeckers

Green woodpeckers
feed on ants

Wood ants feed
on spiders

Spiders feed
on flies

Flies feed on
garbage

Decaying plant and
animal matter

3

Sea-birds
eat herring

Man eats
herring

Dogfish eat
herring

Herring feed on
copepods

Copepods (small crustacea)
feed on diatoms

Diatoms (microscopic plants)
nourished by phosphates from decaying plants and animals

Decaying plants and animals

CHAPTER VI

THE CRADLE OF LIFE

All are agreed that life began in the sea, that for millions of years the only living things were found in the sea. In this chapter Dr. D. Dilwyn John and Professor M. W. de Laubenfels give us accounts of life in the sea to-day from two points of view

LIFE IN THE SEA

by

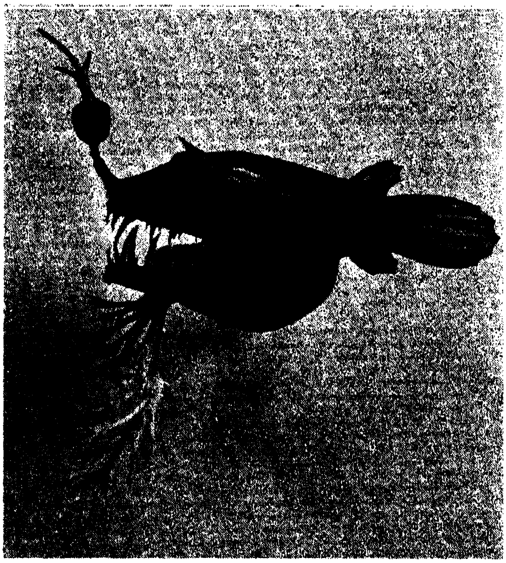
DR. D. DILWYN JOHN

THE sea occupies more than two-thirds of the surface of the globe. On the average it is over 2½ miles deep. There is a shallow fringe of about 100 fathoms around all coasts, called the Continental Shelf, which varies from four or five miles to one hundred miles in width. Beyond it there is a steep slope to a thousand fathoms or more, known as the Continental Slope. The Continental Slopes form the sides of the great ocean basins. The further slope from the bottom of the Continental Slope to the floors of the ocean abysses, with their average depth of 2,300 fathoms or 2½ miles, is very gradual. The greatest depth is more than twice the average, being 5,350 fathoms or 32,000 feet. If Mount Everest were sunk in the deepest part of the sea its peak would be half a mile below the surface.

Great pressure and utter darkness rule in the abyss. At the surface of the land we are subjected to fourteen pounds of pressure to the square inch; it would be three tons at the bottom of the deep sea. Light is absorbed by water. Traces of it may penetrate the clearest water to about 600 fathoms but all beyond is in utter and complete darkness so that a photographic plate exposed there for days or weeks would be unaffected.

Such is the setting that much of the sea offers for life.

The pioneer of the study of life in the sea was Edward Forbes, who a hundred years ago occupied himself with collecting animals from the sea bottom with a dredge, in the first place off the British coasts and then in the Mediterranean. He gradually went deeper and deeper and reached at last to 200 fathoms. He brought starfishes and other animals back from that depth, but, picturing the stupendous pressure and the eternal and complete darkness in the great depths that lay unexplored beyond, he "conjectured that the zero of animal life would be found somewhere about 300 fathoms"; and he named the region beyond that depth the Azoic, or Lifeless Zone.



Linophryne arborifer, a deep-sea Angler-fish from the Atlantic, living at a depth of 273 fathoms. The lantern-like organ on the front of the head is luminous and acts as a decoy to lure other fishes within range of the vicious teeth. The bushy barbel hanging down from the chin is possibly luminous also, and may in addition, act as an organ of touch.

Amphilectus challengeri, a deep-sea sponge from 2,000 fathoms with a beautiful plant-like form. Deep-sea animals are always unusual in form, sometimes of a grotesque shape, often surprisingly beautiful. (One-fifth natural size.)

It was some time before the prejudice was overcome. The fruits of two kinds of enquiries served to remove it. On the one hand British and Norwegian scientists continued to dredge the sea-bottom and went to ever greater depths and did bring back living animals. The second contribution came from practical men, for their attention was, for the first time, being directed to the bottom of the deep sea. It was proposed to use that lying between Britain and America to lay a telegraphic cable. Each government, the British and the United States, sent out sounding expeditions and they were armed with sounding machines devised to bring back samples of the sea-bottom.

As time went on it became clear from the things brought to the surface in the naturalists, dredges and entangled in the wires of the sounding machines that there was life as deep as, and deeper than, 2,000 fathoms—that there was, in short, no azoic or lifeless zone in the sea. The Challenger Expedition, 1872–76, which followed, shewed that life was abundant in all seas at all depths. The explorations and researches of this expedition have been described as "marking the greatest advance in the knowledge of our planet since the celebrated geographical discoveries of the fifteenth and sixteenth centuries", those of Columbus, Vasco da Gama, and Magellan; for they made known the nature of the hitherto unknown two-thirds of the globe.

It is now generally accepted that life first arose in the sea. No man can say how it came about but there are the following and other reasons for supposing that it was in the early seas of our cooling planet. (1) The oldest animal fossils known are of marine animals. (2) The sea is far richer than the fresh water and the land in the lower, the more primitive, forms of life, and it seems a fair inference that those forms arose in the sea and that the land was colonized when evolution had proceeded further. (3) The animal kingdom is divided into seventeen great natural groups called phyla; all are abundantly represented in the sea, five of them are exclusively marine. So, the sea is thought to be the cradle of all life. All living things on land are regarded as descendants of forms that once lived in the sea. Their ancestors colonized the land, probably using the fresh water as a road to it, becoming modified by the slow process of evolution for life, first in fresh water, and then on the land and in the air on the way. The birds of the air, the fleet mammals of the earth's plains and jungles, trace their ancestry back to things which crawled and swam in the sea. And man himself, in striving to master and understand the sea, is exploring his far-away birthplace.

The Eel is an animal which has half accomplished the transition from land to sea. It spends most of its life in our fresh waters; but when the time comes for it to reproduce itself, which is when it is anything from five to twenty years old, it goes down to the sea. All those from European waters go far away to the deeps of the Sargasso Sea and there shed their eggs and never return. Their young make the long reverse journey, taking three years to do so, ascend our rivers and, in time, repeat the story of their parents. The journey to the sea for the most important act of life, that of reproducing and thus perpetuating it, is surely a return to the original habitat.

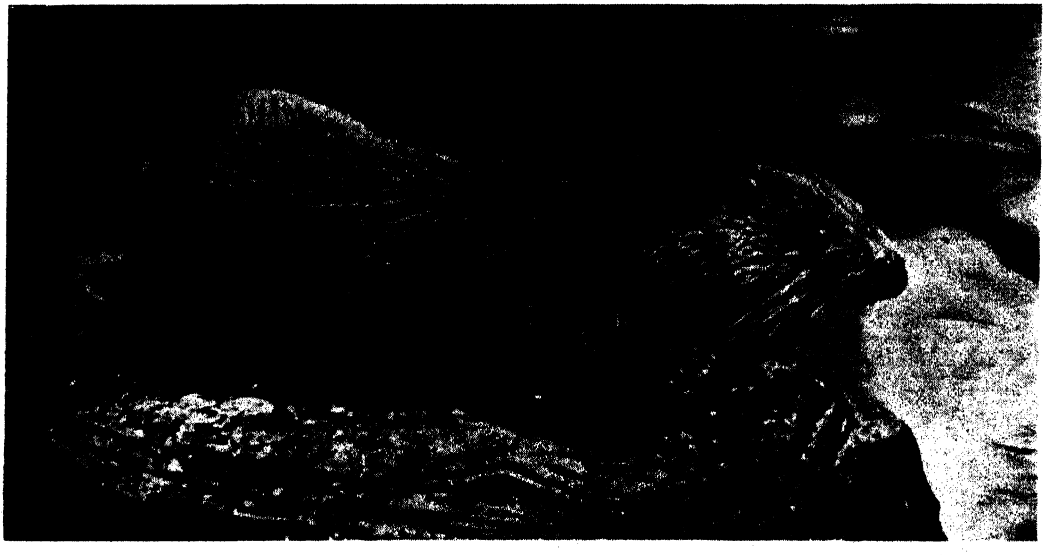
Let us now look at what kinds of life there are in the sea. It is almost true to say that all kinds are represented; it is certainly impossible to describe them all, and impraticable to describe any except in general terms. The lowly and the minute, the microscopic single-celled animals called Protozoa, are there in vast numbers and rich variety. Sponges, which may be regarded as loosely organized colonies of single-celled animals, abound. A step higher in complexity

The ocean bed is, over large areas of the globe, made up of the countless skeletons of microscopic animals which lived in the upper layers of the sea. (Magnified 5 times.)

of form and in the scale of evolution are the sea-anemones and jelly-fish, belonging to a group which included reef-building colonial forms like the corals. They are more highly evolved because they possess what the others do not, a body-cavity and a mouth which leads into it. But, even though it is an advance, it is a simple form of life.

There is a bewildering array of the more complex invertebrates, those which have heads and perhaps limbs and recognizable nervous and circulatory systems. The majority belong to three great groups, the Worms, the Crustacea and the Mollusca. The Crustacea include the prawns and shrimps, the crabs and barnacles, animals with jointed limbs. The Mollusca are the shell-fish. Leaving the invertebrates and ascending to the vertebrates, there are the best-known of sea-animals, the countless fishes.

All the great groups so far mentioned—the Sponges, the Jelly-fish, the Worms, the Crustacea, the Shell-fish and the Fishes—have colonized the land, or the fresh waters of the land, or both. There are sponges and jelly-fish in our ponds and streams, but they are few and small and not well-known. The ubiquitous earthworm is a relative of the bristle-worm found on beaches. The terrestial wood-louse is, like the sand-hopper of the shore and the crab of the sea, a crustacean. And the whelk and the garden

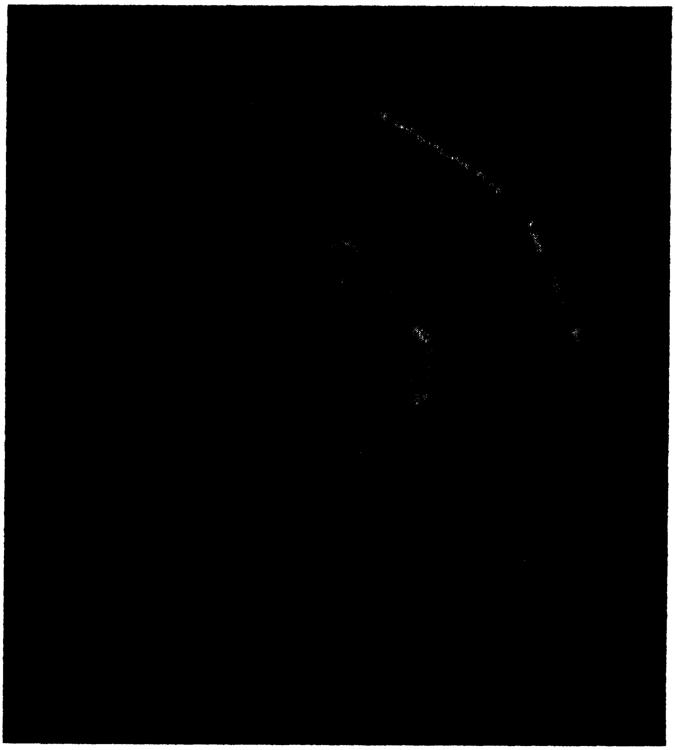


The European Otter *(Lutra vulgaris)* lives mainly in the water, feeding on fish.

snail are both molluscs. Freshwater fishes are related to, and derived from, marine fishes.

But there are in the sea great groups which have arisen and multiplied there and yet have never succeeded in creeping up estuaries or in getting a foothold ashore. No one has seen a starfish except in or by the sea. It is the representative of an enormous group—the Echinoderms—all the members of which are five-rayed like itself, having a mouth in the centre and five arms or rays radiating from it like the spokes of a wheel from the hub. It is a highly successful group in the sea, being found on all bottoms from high-tide mark to the greatest depths. But it has not begun to come ashore. There is one species—one only of many thousands—which can tolerate the brackish water of mangrove swamps. It may be that it is the spearhead of a new invasion of the land, for there is no reason to suppose that evolution has stopped.

On quite the other hand there are animals in the sea which came from ashore. The whales are an example. They are mammals,



Aurelia aurita, the common European jelly-fish, seen from below. From the centre of the umbrella-shaped body spring the four large tentacles. The white horseshoes are the reproductive organs. The sensory canals radiate to the outer edge, which is fringed with small tentacles.

(Photo by Douglas P. Wilson.)

These Black Angelfish *(Pomacanthus aureus)* swimming among corals, gorgonids and sponges, represent two of the classes of marine life known respectively as nekton and benthos.

(Courtesy of Fish and Wildlife Service, U.S. Department of the Interior.)

The ancestors of the seals left the dry land to return to the sea.

being warm-blooded, sucklers of their young, having essentially the same body organisation as all other mammals. Now there is no doubt at all that mammals were evolved on land; and there can be no doubt either that the whales are derived from that stock through ancestors which took to going to sea. Most of the links in that ancestry do not survive and remains of them as fossils have not been found. They are missing links. Whales are completely aquatic—they never leave the water. Seals, which of course are also mammals, may be regarded as having travelled a little way along the journey taken by whales. They have gone back to sea, they get their food entirely from it, they move most easily in it; but they keep, as it were, a foot ashore, they rest and breed on land.

In tropical regions a few insects even have adapted themselves to a life in the sea.

The general economy of life in the oceans is essentially the same as that on land. On land all animal life depends ultimately upon plant life. There are of course purely carnivorous animals but they must feed on herbivores. The herbivores feed on plants and they, in turn, depend on inorganic salts in solution in the soil, on gases in the air, and on sunlight. All this is paralleled in the sea; all animal life there is ultimately dependent upon plant life. The most important plants are not the most obvious, the seaweeds, for they are of course confined to the sea-shores. The deep oceans have no seaweeds and yet they have their pastures. They are in the form of single-celled plants such as Diatoms which float in the surface waters, i.e. in the presence of light, and feed on salts and gases in solution in the sea-water. So the food chain is the same at sea as ashore: mineral salts and gases—plants—animals.

Diatoms are not the only plants of the open sea but they may be taken as an example. They occur in enormous numbers so that although one is too small to be seen by the naked eye, they may colour the sea green. Each plant is encased in a siliceous skeleton which survives when it dies, for silica is nearly insoluble in water. A constant rain of these skeletons falls to the bottom and where diatoms are particularly numerous, as they are in the Antarctic and in the North Atlantic, the bottom of the sea is buried deep, no one knows how deep, with Diatom Ooze—an accumulation of their minute skeletons.

The floors of the shallow seas are made up of materials derived from the nearby land—of muds, sands, silts and so on. But those of the deep oceans have been found to be differently composed and of other origins. They are oozes built up from the rain of materials through the waters above. The Diatom ooze already mentioned is an example. That is of plant origin. Vast areas in the Atlantic and Indian Oceans are covered with the limey skeletons of minute animals which have lived in their upper waters. The most abundant member is called *Globigerina* and the ooze has been named after it—*Globigerina Ooze*. That is a bottom deposit of animal origin. Fifty million square miles of the deepest sea-bed, chiefly in the Pacific, are covered with red clay which is believed to be an accumulation of volcanic dust that has fallen on the sea. None of the oozes, these bottom deposits, is pure. Each is named after its predominant constituent.

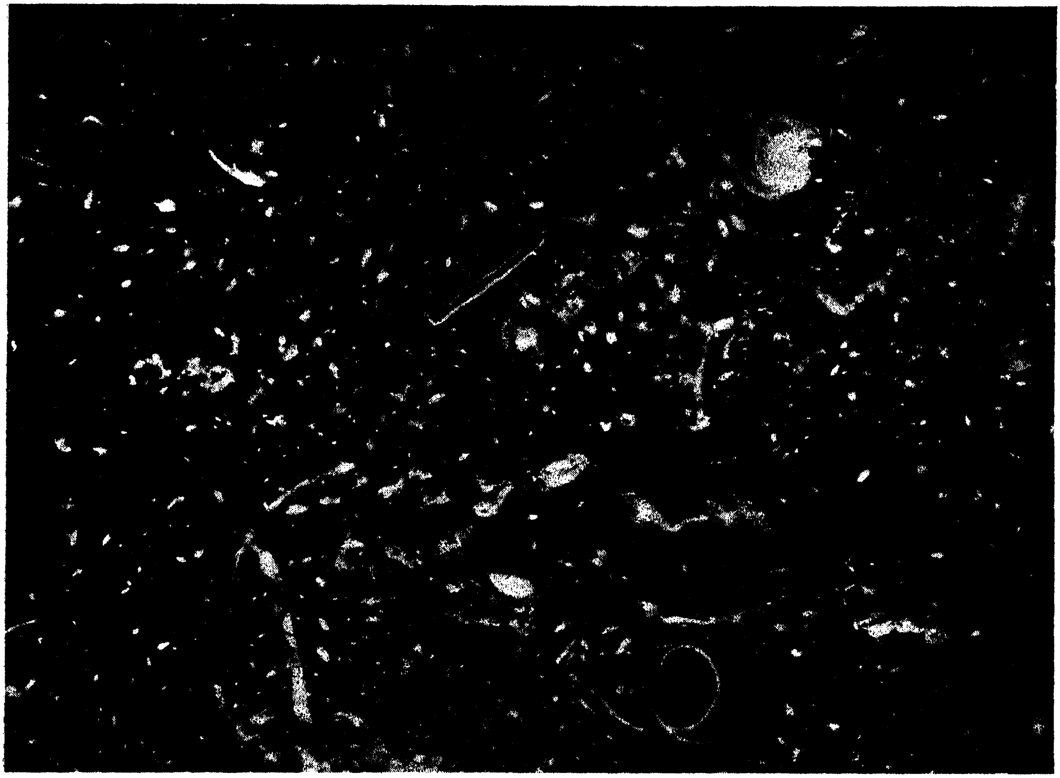
The very numerous forms of life in the sea are divided into three categories according to their way of living. Those forms which live on the bottom, whether attached to it like sea-anemones, or crawling on it like starfishes, or partly buried in it like cockles, are called Benthos.

Those which swim actively through mid-water, or at the surface, like most fishes, like squids, and like dolphins and whales, are called Nekton. And the third category—those which live in midwater or at the surface but are not strong enough to swim against currents, but drift with them—are called Plankton. This category includes a vast horde of things—all small, many minute. Among them are the Diatoms and *Globigerina* which we have noted as builders of deep oozes on the sea-bottom; and many other single-celled organisms like them.

Of higher animals the most abundant are the very small crustaceans known as copepods. There are very many species from sea to sea. And there are many other kinds of organisms in the plankton: it would be tiresome to enumerate them. It is plankton which causes luminescence in the sea at night. Movement of the water stimulates it so that it is often strong in the wake of a ship or a boat.

There are many organisms in the sea that spend the early part of their life in the plankton, i.e. live a floating life; and the latter part of their life in the benthos, i.e. on the bottom. And they have quite different shapes at the two stages. A starfish, for example, is when adult a sluggish heavy animal with five or more arms radiating from a common centre. It is very much a member of the benthos – is not capable of leaving the bottom. But it spent its childhood in a very different way and had a very different appearance then. It had a right and a left side, a head and a hinder end: in short, it was bilaterally symmetrical (as we are) not radially symmetrical as the adult starfish is. It was very small, almost microscopic, and transparent apart from a few pigment spots. And it was a member of the plankton; it lived a floating life in mid-water. It fed on the smaller members of the plankton – the truly microscopic members. It was not a bit like a starfish to look at; and when first discovered it was thought to be an entirely new kind of animal and was given a new name.

The process by which it turns into a starfish is quite as strange a metamorphosis as that which changes a caterpillar into a butterfly. The rudiment of the adult appears on the left side of the larva and grows there during the larval life. The final change takes place in a few hours. The larva leaves the upper waters and settles on the bottom; the adult rudiment absorbs the larval body and the floating member of the plankton becomes the crawling member of the benthos. It is a strange sea-change, and is but one example which must stand for thousands.



Plankton includes both the drifting and swimming population, plants as well as animals, of the seas and freshwaters. It plays a very important part in the economy of nature as the chief food of many of the larger animals. Some of the wide variety of organisms contained in the plankton can be seen in this picture. (Magnified 5 times.)

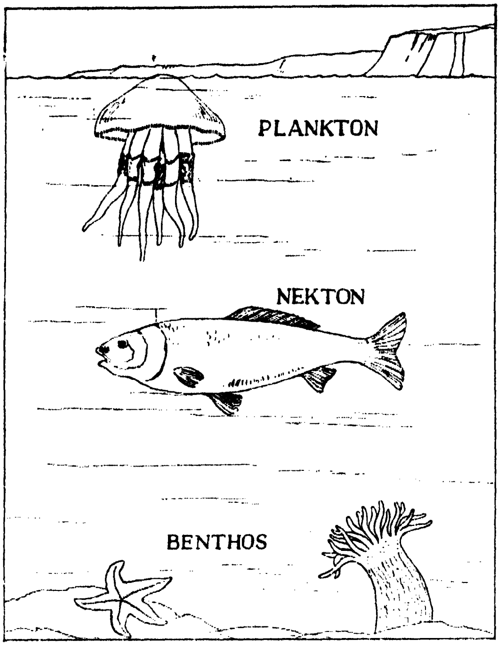


Diagram illustrating the three groupings of marine organisms: plankton, those that drift in the currents, nekton, those that swim freely, and benthos, those that live on the bottom.

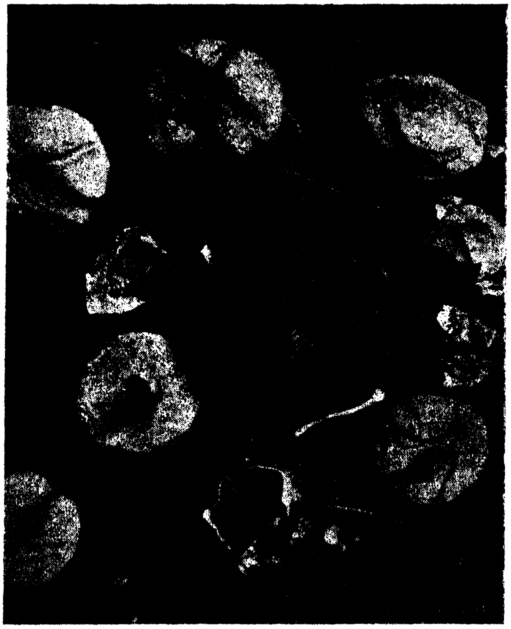
Nearly all the animals that you may find on the sea-shore were once, when they were very small, members of the plankton. This is true of sea-urchins, worms, crabs, lobsters, barnacles, mussels. They were all minute when they were planktonic; and they were all of very different shapes to those they have as adults; they were of shapes fitted for a drifting life. The biological advantage of the drifting planktonic young stage is that of dispersal of the species. Many bottom-living creatures are sluggish and if their young grew up around them there would soon be local overcrowding. The species spreads itself by being planktonic when young. The young stages are carried everywhere by tides and currents, and the survivors settle down where they happen to be when the time comes for them to change their form to that of the adult. They will probably be far away from their unwitting, uncaring parents then.

I used the word survivor. It is fully justified. In some species of sea-urchins each female lays several millions of eggs each season. Since the adult sea-urchin population remains constant, it is, on an average, only two of these millions from one mother that survive.

Apart from planktonic larval stages there is a large—an immense and enormous—permanent plankton population present in all seas in all parts of the world.

And now for a word or two about the distribution of life in the seas – that is, the Geographical Distribution. There are a few animals that have a distribution that is nearly world-wide. An example is the Heart Urchin—the one that may be washed up in thousands on sandy shores after storms have dislodged it from the bottom in which it lives embedded. It is found in shallow water in all parts of the world except the Arctic and Antarctic. But that is exceptional.

Most animals have a relatively narrow range: they can live, for example, only within certain temperature limits. So it is broadly true to say that the polar seas have different animals to temperate seas, and they again have different forms to those of the tropics. Seas of the same

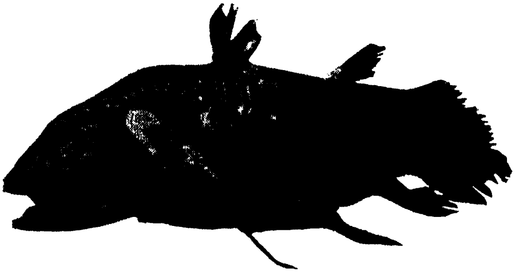


A group of Heart-urchins *(Echinocardium cordatum)* thrown up on a sandy beach on the south coast of England. These urchins burrow in the sand, from which thousands are often dislodged by storms and left stranded on the beach. The central specimen still has its covering of spines. The others around it are denuded of them.

Beds of mussels *(Mytilus edulis)* exposed at low-tide. A mile of shore may bear 50 million or more of these, each one the sole survivor from a brood of many millions. Most animals found on the shore spend their larval life swimming in the sea. For every animal so found a million or more larvae have lived and perished. So we can gain a slight idea of the teeming and uncountable millions that make up the population of the seas.

nature which are widely separated have different faunas. The tropical seas of the Atlantic on the one hand, and of the Indo-Pacific on the other, have no connection and they have different faunas. The same is true of the Arctic and the Antarctic. But there is one category of life which is an exception and that is the life on the floor of the oceanic deeps. There the conditions are the same the world over: even low temperature, great pressure, utter darkness; and the forms of life which live at those great depths have, so far as is known, a very wide—often, a world-wide—distribution.

It might be supposed that nowhere in the surface seas were there sharp boundaries between one kind of water and another but that all changes were, because of ready water-mixing, gradual. It is not so. There are some quite sharp boundaries. The sharpest of them is that which forms the northern boundary of the Antarctic Ocean. If you are steaming south in high latitudes, and if you are armed with a thermometer and keep on taking the temperature of the surface water, you will be able to say when you enter the Antarctic: there will be a sudden, a sharp fall of temperature of 2° to 3° C. That is so in all longitudes and the line along which it takes place is called the Antarctic Convergence.



Latimeria chalumnea, a fish caught in 1938 off East London, South Africa, at a depth of 40 fathoms. It belongs to a group of fishes which was believed to have become extinct a very long time ago (one-twentieth natural size).

It comes about where cold, and therefore heavy, Antarctic surface water meets the warmer and, therefore lighter, water of the Sub-Antarctic. Their very different densities do not allow of ready mixing. Both bodies of water have movement. The Antarctic has a northerly component in its movement and it sinks below the sub-Antarctic and continues its flow northwards below it—it can indeed be traced in the Atlantic, at a deep level, to north of the equator.

The boundary is easily traced with a thermometer. It can be as readily, if not as precisely, determined by a zoologist with a townet, if the zoologist knows, for example, the different species of prawns called Euphausians which live in the plankton of those seas. They are so numerous in the surface waters that his net will always catch some. If, in the neighbourhood of the convergence, he takes the species called *Euphausia vallentini* or *Euphausia longirostris* he is in sub-Antarctic water. He will have crossed the convergence and be in Antarctic water when his net brings back *Euphausia frigida* and not *Euphausia vallentini* nor *E. longirostris.* In other words, the physical boundary is a sharp biological boundary as well: different kinds of animals live on either side of it. Some can live on both sides; but to many it is a limit: the northern limit of Antarctic species, the southern limit of sub-Antarctic species.

It would be wrong to conclude without in some way stating that much remains to be discovered about life in the sea. Zoologists received an enormous surprise in 1938. A South African trawler brought up from 40 fathoms near East London a kind of fish perfectly well known to science as a fossil, which had been supposed to be extinct for 60,000,000 years. It was much more surprising than finding a living mammoth on land would be. Indeed the equivalent ashore would be a living Dinosaur.

We have no right to suppose that that is the last secret the sea has to yield.

Two species of *Euphausia* which mark the Antarctic convergence. On the left, *E. frigida*, on the right, *E. valentini*. (One half natural size.)

LIFE UNDER THE SEA

by

Professor M. W. DE LAUBENFELS

Fairyland has been thought of as a child's monopoly, and of course—quite imaginary. How ridiculous to suggest leaving this familiar world and visiting another, where—light as a feather—one makes forty-foot leaps and walks through purple crowds of death-trap animals in safety, while scaly scarlet dragons swirl round one's head. The land that has no sky—how utterly fantastic.

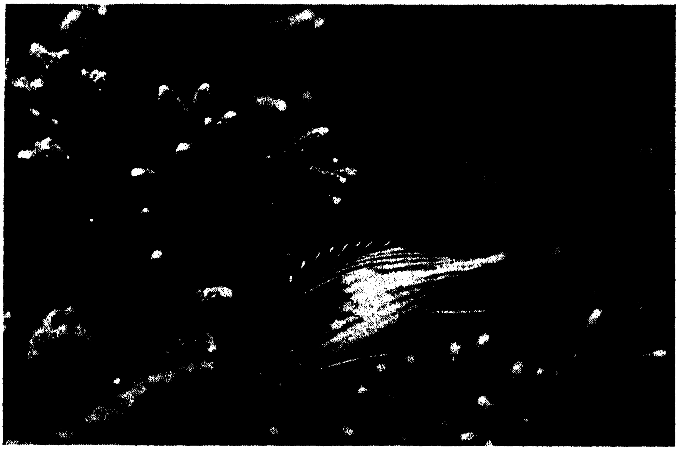
Fancy a grown man claiming that all one needs to make this visit is a magic helmet – like the old fairy stories about magic carpets and wishing rings . . . . Well, here's the claim. It is as true as it is lovely, and as lovely as a fairy story; I have been there, myself, in real genuine wonderland.

The magic helmet weighed about eighty pounds, and, like a knight with his squires, I required much help to don it. The load hurt my shoulders, where the helmet's edges rested. The ladder led down into the warm salt water and my legs were already wet as I looked back into the boat through the helmet's plate glass visor. Already the everyday world was being shut away. I started down the ladder. I let go, and sank—slowly.

Slow, always slow. Everything on the ocean floor is slow. It is easy to do it slowly, but one can't—no, simply can't do it fast. Put your hand in a tub of water and observe for yourself—move it slowly, and the water slips away, light as a feather. Now hurry your hand, and feel the water turn to stone. Water can be so steel-hard against speed, that a fast-whirling screw pushes a steamship.

Slow, but marvellous. I don't walk upright, but leaning forward, pushing back with my feet like a horse pawing the ground with impatience. Push just a little bit harder, and I soar up into space—over a coral "head" as big as a motor car. I seem to weigh nothing—but all this in very slow motion. Without my helmet I would float to the surface.

Above me is a ceiling, not a sky—a chased and burnished silver ceiling, the undersides of waves that are everlastingly in motion, changing shape and tossing gleams about like mercury. Yet once in a while one may be on the shallow sea bottom on a really calm day. Then one can lean one's head far back, and look straight up. Directly overhead is a curious circle with the whole seascape inside it. The lighthouse to the west is on the west rim of the circle, pointing in, not up. The steamer which is cruising past at the south seems to move like a toy around the south side of this circle that is the horizon. All of the beams of light appear, but so bent when they go from air into water that one looks nearly straight up in order to see the island that is actually due north of one. Hold a stick half into water, and observe how this air-water junction bends the appearance of things.



A Squirrelfish *(Holocentrus ascensionis)* darting into the shelter of a staghorn coral. Active mainly at night, this fish quickly darts into its hiding-place in the coral if disturbed. It has a red head and longitudinal red stripes.
Courtesy of Fish and Wildlife Service, U.S. Department of the Interior.

There is a warm-snow floor, paradox of the tropical sea. The ground is dazzling white, soft as snow, but made of coral fragments, ground up by waves into pure white sand. Silver sky and snowy floor, but the distance on all sides is rich blue-green. My fingers are clear to see, sharp outlined as though in air, but the bushes twenty feet away are hazy; with more and more distance is lost, as by magic. This is fairyland.

Bushes? Odd bushes that are animals, not plants, but branched just like bushes. Gaudy purple bushes which bend like alder when I brush against them—these are gorgonians. Every branch is the crowning achievement of a thousand co-operating little devils. Yes, each polyp is truly a tiny demon, small as a sand grain from the beach, but a torturing death-trap to other small animals. Some of the yellow-green bushes are brittle as glass, and ruinous to ships' bottoms. These are coral, and they, too, are community enterprises. The sand-grain-sized devils of gorgonian and coral lie in wait like traps in the forest, but catch and kill by means of a terrible poison. I have felt this toxin: a little, but that was all too much: it sears and burns like boiling oil, but paralyzes instantly. I have seen a fish touch one of these devils, and go rigid and helpless in agony, all in a second.

"Coral-pink" coral is rare—the dead skeleton of most coral is snow white, but when the flesh of the myriad polyps is in place, it is yellow, or greenish.

How can it sink ships when it is so amazingly brittle? Make a pile of bricks, and see how easily the column topples when you bump it—but you can set a house up on top of it. The great ship hits the reef, where coral branches point in all directions. Some are sure to point directly into the ship's bottom—incompressible as a pile of bricks, puncturing steel plates and sinking full-sized steamships. Remember, too, that the coral devils keep multiplying, building up new reefs where the sailors thought there were none. Perhaps Davy Jones and the corals are partners—cronies in crime.

Purple bushes, yellow-green bushes, growing on a snow white floor—and among them the sponges grow—each its own color: vermilion, orange, golden, green, azure blue and violet, like an artist's palette, or bits of the rainbow. Sponges shaped like barrels, and as big; others like candlesticks, vases and graceful fans. Then the velvet-black bath sponges, still wearing their meat and skins. The sponge in your bath is merely the bare bleached skeleton of a once-living animal—a harmless one, that lived on microbes that no one else wanted.

Isn't it dangerous to be thus under the sea? Not more so than to cross a busy metropolitan avenue. To be sure there is the pounding in the ears from the pump, away up there on the deck of the boat, where a man is working the pump handle steadily. Every increment of air from the pump hits the ears so that after a half-hour or thereabouts a headache results. Try cupping your hands and then clapping both ears at once, over and over, cupped palms against the ear cavities. It will take only

A corner of fairyland with Yellow Goatfish *(Mulliodichthys martinicus)*, and Yellow Grunt *(Haemulon sciurus)* in the foreground.
Courtesy of Fish and Wildlife Service, U.S. Department of the Interior.

During the day the Schoolmasters *(Lutianus apodus)* haunt in groups the great masses of coral "big as a motor car". At night they separate and frequent the surface of the sea to feed.
Courtesy of Fish and Wildlife Service, U.S. Department of the Interior.

Another corner of an underwater garden of corals and overhanging Gorgonids, with a Yellowtail fish *(Ocyurus chrysurus)*.
Courtesy of Fish and Wildlife Service, U.S. Department of the Interior.

A Red Grouper *(Epinephelus morio)* among the corals and Gorgonids. In colour this is one of the most changeable of fishes. At rest it is banded to harmonize with its surroundings. When active it takes on a plain colour, often almost grey.
Courtesy of Fish and Wildlife Service, U.S. Department of the Interior.

a few minutes to produce this same headache.

Many people have heard of a danger called "bends" in connection with diving in deep water. The pressure which sends air all the way down to a diver, and even forces exhaled air out of his helmet (it makes a parade of bubbles past his ear, up to the surface), is so great when deeper than fifty feet that nitrogen dissolves out of the air into the diver's blood. Release the pressure suddenly, as by rising to the surface very rapidly, and the nitrogen comes out of solution as bubbles which can clog a vein, thus causing injury, or even death. This danger is forestalled by a gradual return to the surface; one may spend half an hour coming back up from a hundred-foot depth. Better yet, stay in shallow water.

The danger of sharks is not great in the tropical Atlantic regions. They are stimulated to eat only that which smells or tastes "right", and the scent of man doesn't seem to appeal—that is to say, of unwounded man. A bleeding wound is a double danger, because its stimulus to the shark is a push button; the stream-lined gray fish then is a killer. Don't get wounded in the water with sharks! Thus it happens that the fish called the barracuda is the real danger in Bermuda, the Bahamas and the tropical Atlantic in general. (Some Pacific sharks don't wait for the barracuda to start matters.)

Barracudas are dangers, because—as few fish do—they will take bites. Move ever so slowly when the pike-like, sharp-prowed barracuda slips past! His push-button is speed, eighteen miles an hour, the pace of those fish that he commonly lives on. I could catch barracuda with metal or wood, red, yellow or blue, any shape or construction, just so it was going eighteen miles an hour. True, a human swimmer never reaches that speed, or even comes close to it—not his body, or rate of over-all travel—but the swimmer's arms or legs may swish through the water at exactly that speed. The reflex-governed barracuda reacts like a gun to a trigger.

So far from being dangerous to man, most of the fish are the fairies. The ones which live up near the surface have the mortal obligation to be inconspicuous in color, or else, as tempting targets, to be first to vanish down the gullets of yet larger fish. Fish who can instantly find shelter among the coral heads dare to be vividly colored. It appears that in nature everything is

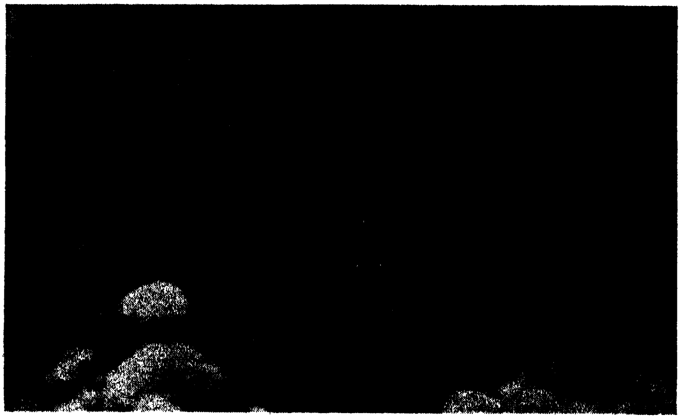
The Great Barracuda or Sea Wolf *(Sphyraena barracuda)* feeds on fish and squid, tearing out lumps of flesh with its wicked teeth.
Courtesy of Fish and Wildlife Service, U.S., Department of the Interior.

as gaudy as it can be and yet live. For example, the angel fish, lovely in the way that story-book angels are painted, are round as a plate in silhouette, but are almost paper-thin from side to side; they dart between the poisonous, stinging coral twigs and find safety. Their gold and azure scales are lovely and striking. No oil painting can do justice to the gleams that reinforce their colors, cold-fire reflections from their metallic-appearing scales. Fish striped red and green, fish colored violet and yellow, fish with patterns to inspire an artist, fish that must be seen if anyone is to believe they could possibly exist—these are the nymphs or sprites of the coral groves.

Yes, there is some sea-bottom danger: sea urchins, like huge black-purple pincushions, but pinpoints out—they are dangerous. Their spines are more like needles than pins, six to ten inches long, the hundreds of brittle spines protude in all directions. Just touch a spine, and it stabs you, then breaks off. Let's pull it out with forceps—but no, only the bit between the tool's tip comes, the rest stays buried deep, festering, an ugly, painful, and dangerous wound. This is always imminent, because underwater currents lift one like trash paper in the eddying winds of a city street—as dry leaves are swirled in gusty, sunny autumn. A gentle little current, perhaps

The fish in the centre of the picture is a Runner *(Caranx ruber)*, a terror to small fish. The smaller fish beside it, with the longitudinal bands, is a Porkfish *(Anisotremus virginicus)* which is searching the Runner to clear it of parasites.
Courtesy of Fish and Wildlife Service, U.S., Department of the Interior.

A school of pale grey fish known as Sailor's Choice *(Haemulon parra)* with the striped yellow Grunts *(Haemulon sciurus)* accompanying them.
Courtesy of Fish and Wildlife Service, U.S. Department of the Interior.



Red Parrot fish *(Sparisoma abildgaardi)*, with white spots, resting among coral and bushlike Gorgonids.
Courtesy of Fish and Wildlife Service, U.S. Department of the Interior.

dragging below a surface wave, suddenly and gently but irresistibly picks up the diver and puts him over here—next over there. Brace, push, . . . always brace and push. Actually, I often carried a crowbar in lieu of a cane, glad of its weight, and it was also a tool to pry specimens loose. Suppose a current sets one against a sea urchin? The big black ones are the worst and most abundant.

Only their spines are bad for man, otherwise these urchins are harmless scavengers.

The first time I ever went down to the sea bottom was unpleasantly thrilling. No one told me the importance of having my head out in front of my hips, body in the forward-leaning position, when falling through the water. I tried to fall erect, and the great weight of the helmet instead took me gradually backward. I lit on the bottom, flat on my back, spread like a victim ready for mediaeval torture. That was instantly the simile that struck me.

At street fairs or variety shows one sometimes sees the breath-taking feat of skilful knife-throwing. The fat lady performer leans against a wooden wall. Across the stage the knife-thrower stands, and hurls the heavy knives. With thud upon thud they land, point first, sticking in the board until they make a palisade around the intrepid (or unimaginative) William Tell's daughter.

Thus I felt on this occasion! Beside me, around me, on all sides was a chevaux-de-frise of needle-rayed sea urchins. Yet, like the lady performer, none of the sharp points hit me as I fell among them!

At last, saturated with the strange, fantastic beauty, and weary of the pounding in the ears, I go back to the dry world. It is easy to find the boat; just follow the long black air hose. Then there is the boat's dark hull overhead, like a big, heavy dirigible. I manœuvre until I am right under the ladder, then give an upward spring, and coast five, ten, twenty or more feet upward to the ladder's lowest rung. Then I climb, up and up, suddenly growing immeasurably heavy as I break water and emerge into the non-buoyant air. The pump stops, and voices come dimly through the thick helmet. Now someone helps me lift off its eighty pounds, so that my normal weight returns—neither burdened nor yet weightless as I had been down below. Safe on the deck—warm, but not too warm, thanks to the trade wind, it feels good to breathe deeply.

Safe? No—one last danger has clutched me, in spite of my armour. Should one call it nostalgia? Dangerous knowledge like that which banished Adam from Eden—I know what beauty lies under the keel. Always and always I shall yearn to return, down with the corals, the sponge gems and fairy fish. Yes, even the urchins are calling me back:

Under the sea, where bushes are beasts;
Gorgonian devils, with live-poisoned feasts.
Angel-fish colored like rainbows with scales;
These are my fairies, but I tell the tales.
Again let me glide with that effortless motion
Over warm coral snow, under warm blue-
green ocean.
Put on my helmet! Who'll pump the air?
Wonderland's calling me back to it, there.

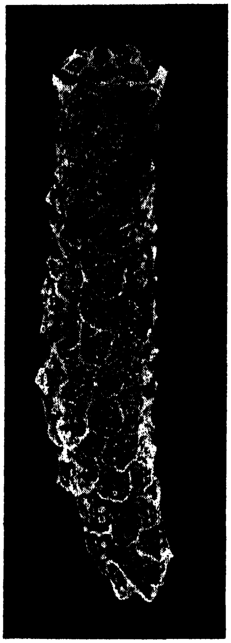
CHAPTER VII

THE FIRST ANIMALS

PROTOZOA AND SPONGES

FROM this point we shall deal with the classification, or taxonomy, of animals, beginning with the simplest and progressing to the highest Primates, the nearest relatives of man himself. This classification reflects the order in which life appeared on the earth, as well as the orderly sequence in which animals become progressively and increasingly more complex or, to use a better term, highly-organised. Thus, in the classification is expressed the evolutionary plan, as well as the close relationship of all animals, man included, both living and dead.

Each stage will raise its own special points, and the taxonomic sequence will be interrupted where necessary to deal with these points, usually by means of articles written by specialists.



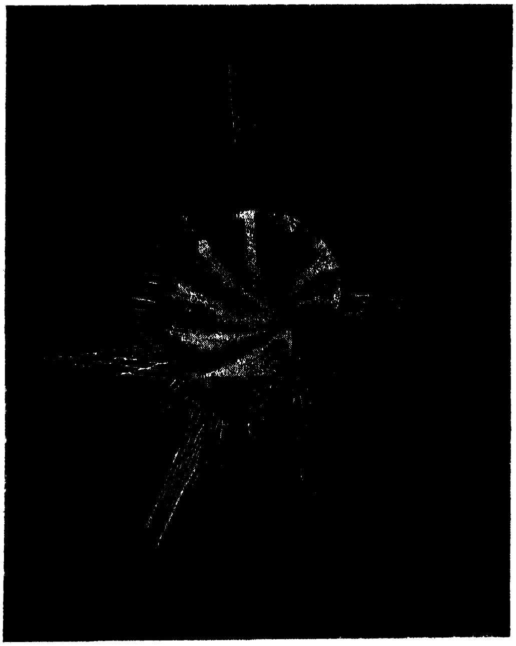
Technitella thomsoni, one of the Foraminifera which clothes its body with a covering of plates cast from the body of a Sea-cucumber. Although one of the lowest forms of animal life, closely related to Amoeba, *Technitella* is able to select plates of a certain size and shape from among the assorted debris in the mud. (Magnified 20 times.)

The Phylum Protozoa

(Proto – first: zoon – animal)

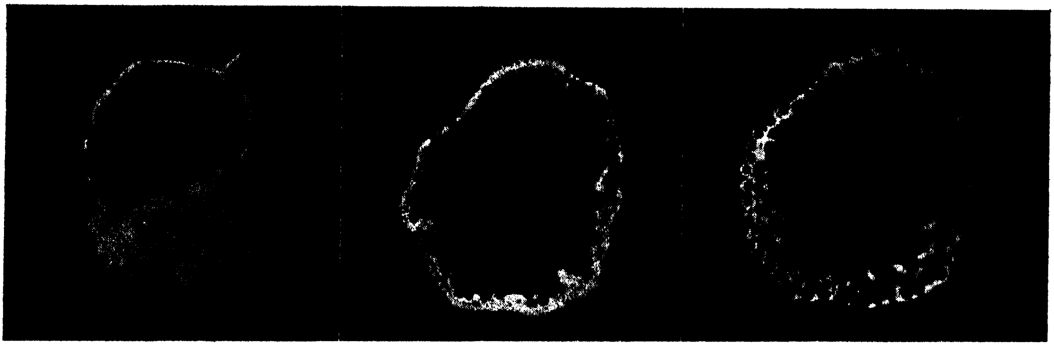
THE UNICELLULAR ANIMALS

There can be no better introduction to the Animal Kingdom than through a study of the Protozoa. Although the great majority of these unicellular animals are microscopic in size, the part they play in the world to-day, as in the past, is a very important one. Their dead skeletons, raining down through the waters of the oceans, are responsible for a large part of the muds covering the floor of the oceans. In the past, skeletons of their ancestors have contributed largely to the building up of the layers of rock of which the land masses are composed. In the seas to-day they comprise a large proportion of the plankton on which higher forms of life

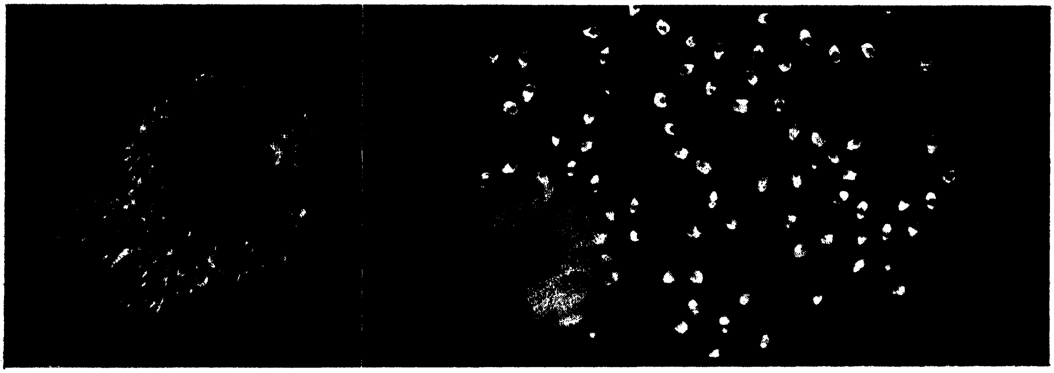


Elphidium (Polystomella) crispum, to show the manner in which the thread-like strands of protoplasm are protruded through the pores, or foramina, in the surface of the shell. (Magnified 20 times.)

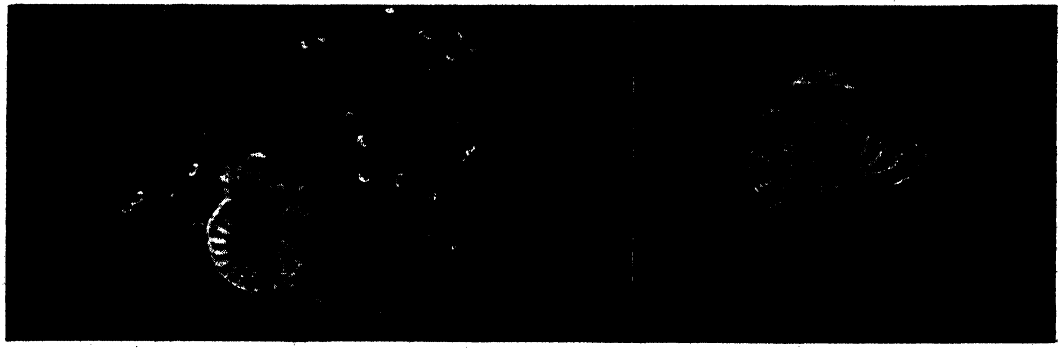
Seven stages in the birth of a new brood of one of the Foraminifera, *Elphidium crispum*. Even in the unicellular animals reproduction is not always simple, although in the more advanced of them, as in *Elphidium*, it is still a process in which the parent body splits up to form new individuals. (Magnified 20 times.)



The first stage (1 p.m., May 22, 1895): A microscopic shell of *Elphidium* (*Polystomella*) *crispum* crowded with the nucleoli of its young showing the "premonitory halo" of pseudopodia (foot-like processes) round the edge.
Stage 2 (6.30 p.m., May 22): The pseudopodia have been withdrawn and the young can now be seen leaving the shell, but are still totally enveloped in the main mass of protoplasm (showing light round the edge).
Stage three (10.55 p.m., May 22): The light (which can be seen distinctly passing through the shell at the centre) indicates the young are leaving the parent, each removing a portion of the original protoplasm.



The beginning of the final stage (11.15 p.m., May 22): The young are here seen leaving the parent, each removing protoplasm as they separate to commence independent existence.
The final stage (11.50 a.m., May 24): The young are here seen having secreted the initial chamber of a shell (looking dark with the nucleus within) and with the first of the spiral chambers projecting(clear).



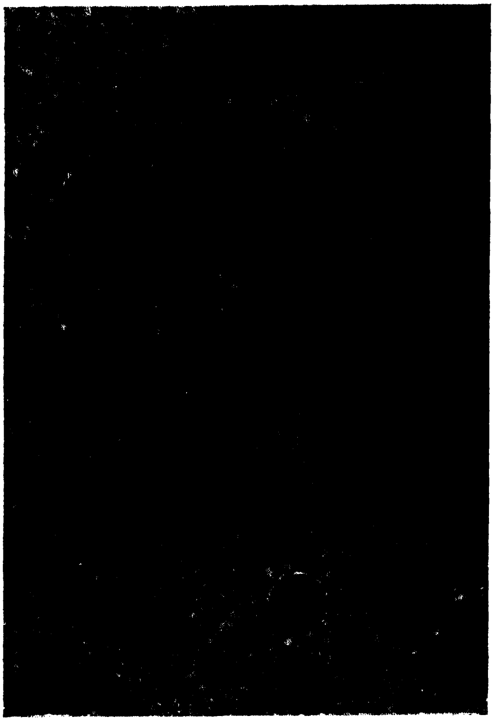
The post-final stage (undated): The young have added a second chamber to the developing shell, which in due course will be discarded and left to sink to the sea-bed, a process which has continued over some millions of years. As found on our beaches among the grains of sand: the empty parent shell of *Elphidium crispum*, one of the Foraminifera, showing the spiral arrangement of the septa, or chambers, and retral partitions having the appearance of ladders.

subsist. And, finally, many of them are responsible for a variety of diseases, such as dysentery, sleeping sickness and malaria as well as many less well-known. In the seas, the rivers and lakes, in the smallest ponds or even in damp earth they are present in countless millions, and it is probably true to say that the body of every one of the Metazoa contains several different kinds of Protozoa at least.

Although we have grown accustomed to thinking of them as simple, the bodies of these one-celled animals are, in fact, very complicated. They perform within a single cell all the functions of living, such as feeding, excretion, respiration and reproduction.

The Phylum Protozoa consists of four classes: the Rhizopoda or Root-footed Protozoa, that move about like Amoeba by pushing out pseudopodia; the Mastigophora, or Whip-bearing Protozoa, with one or more whip-like flagella at the anterior end which, by their lashing movements, draw the animal through the

A collection of shells of Foraminifera, to show the diversity and beauty of form. (Magnified 10 times.)



The large round cells, with the darker nucleus, are *Endamoeba histolitica*, the cause of dysentery in human beings. (Magnified 1200 times.)

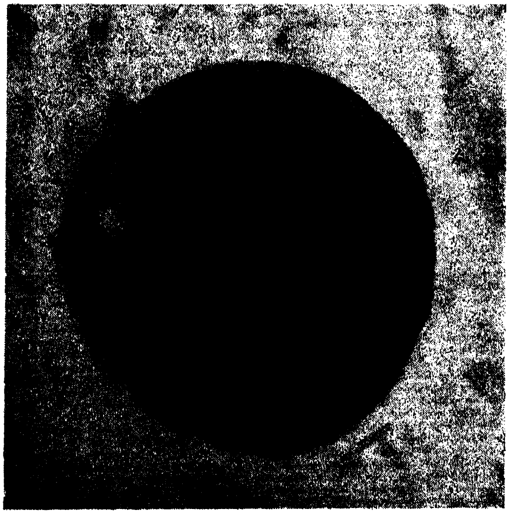
water; the Ciliata, covered with cilia, or hair-like projections of the protoplasm, which propel the body by rhythmic wave-movements; and the Sporozoa, parasitic in the bodies of other animals, which at some stage in their life-history reproduce by spores.

The Rhizopoda include Amoeba and its relatives. They live, for the most part, on the mud, stones and weeds in freshwater and in the seas. Some live in damp earth, and a large group known as *Endamoeba* live in the bodies of higher animals. The human body may contain as many as six *Endamoeba*, most of which live in the large intestine. Of them one only is harmful, *Endamoeba histolitica*, which may burrow into the walls of the intestine, producing ulcers and setting up dysentery.

The majority of Rhizopoda are not naked, like Amoeba, but live in shells, or tests, as they are called, of various kinds. One of the simplest is *Arcella*, which secretes a chitinous shell, dome-shaped above and flat below, with a hole in the centre of the flat surface through which the pseudopodia can be protruded. *Difflugia*, on the other hand, builds a flask-shaped house, or test, made by gluing together sand grains with a sticky secretion from its protoplasm. Another group, the Radiolaria, take up silica from the water and secrete it to form skeletons of exquisite and delicate pattern; while the Foraminifera do the same, using calcium carbonate. Some species of Foraminifera have given up making tests in this way and glue together sand grains and other hard microscopic objects in much the same way as *Difflugia*. Most species of Radiolaria and Foraminifera have pseudopodia extended into long slender filaments and float in the surface layers of the sea. When these animals die their skeletons sink slowly to the bottom and by their accumulation build up the oozes covering the ocean beds.

There are a few species of Radiolaria in which the individual animals remain together embedded in a common jelly to form colonies.

The Mastigophora, or Flagellates, are best exemplified by *Euglena*, responsible for the green coloration of standing water. It has a spindle-shaped body, $\frac{1}{100}$ of an inch long, marked with slender grooves running spirally along it, with a flagellum extending from the anterior end of the body. The green colour is

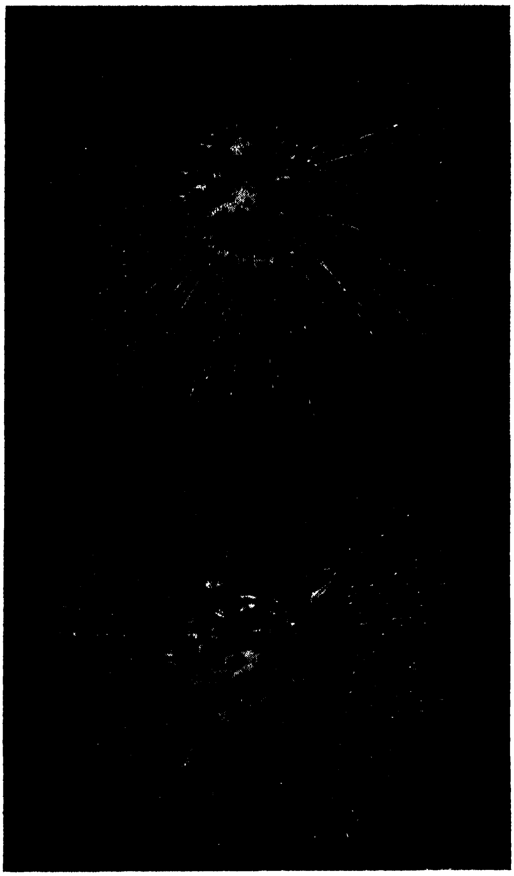


Endamoeba coli, another Protozoan that has taken to a parasitic life in the intestines of human beings but is not necessarily harmful. The central nucleus is clearly seen. (Magnified 5000 times.)

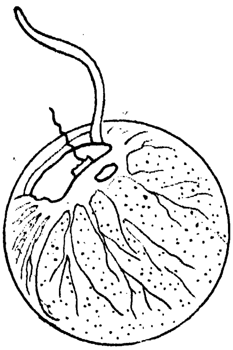
due to the presence of chloroplyll, the green substance characteristic of plants, and the animal feeds in much the same way as plants by breaking down the carbon dioxide dissolved in water, setting free oxygen and converting the carbon into paramylum, a substance allied to starch. This it does only in the presence of light, and so we find near the base of the flagellum a red eye-spot, sensitive to light. It would appear that light falling on this eye-spot causes *Euglena* to turn and travel towards the maximum area of light, an obvious advantage to an animal that can only feed successfully in the presence of light. Here we have an obvious, though simple sense organ.

Some organisms allied to *Euglena* tend to live together in colonies, such as *Volvox*, *Dinobryon* and *Synura*. The first of these has a special interest: it consists of a hollow sphere of cells, each cell having a pair of flagella directed outwards, and the swimming movement of the colony as a whole is brought about by the unified efforts of the flagella of each individual cell comprising it. Each cell in addition manufactures its own food, by means of its chlorophyll, but because there is protoplasmic continuity between all the cells it is likely that there is some sharing of the food so obtained. Here then is a simple case of co-operation, although the cells retain their individuality. Moreover, reproduction is carried out by certain cells only, which become slightly more specialised for this purpose. There is, therefore, a division of labour, some cells, the reproductive cells, being

Noctilica scintillans, a Protozoan living in the sea, and feeding on other smaller Protozoa. Often the sea is coloured orange for miles by countless numbers of them, or at night it may glow with bluish or greenish light. Some idea of their numbers may be gained by the fact that at such times a gallon of water taken from the sea may contain five millions or more of these animals. (Five times natural size.)



Life-like glass models of Radiolaria, showing the glassy nature of the siliceous tests, or shells. Long beaded strands of protoplasm protrude through the holes in the surface from the minute protoplasmic body within, which has secreted the delicate shell. (Magnified 25 times.)



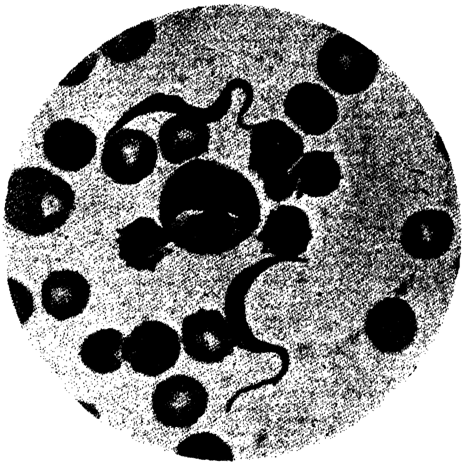
Noctiluca, the marine Protozoan, showing the stout, almost finger-like, flagellum and the thread-like flagellum on the margin of the mouth. (Magnified 30 times.)

concerned only with propagation, and the rest, the vegetative cells, with feeding and locomotion.

The luminescence, often erroneously referred to as phosphorescence, in the sea may be caused by one or other of several different animals, but perhaps most commonly by a species of Protozoa named appropriately *Noctiluca*. This is one of the largest, consisting of a transparent spherical body, .04 of an inch in diameter, filled with a clear liquid and with branching strands of protoplasm visible under the surface. At one point is a mouth, with two tentacles springing from its margin, one thin and the other thick and tentacle-like.

Paramoecium, the Slipper Animalcule, showing the food groove on the lower surface, the short cilia coating the surface of the body, and the two darkly-stained nuclei, a larger meganucleus and a smaller micronucleus. Food vacuoles containing dark particles are scattered in the body, and the two clear, spherical excretory vacuoles are at each end just under the upper surface.

Paramoecium candatum (The Slipper Animalcule), one of the Protozoa found commonly in fresh water, especially in ponds and rivers containing a high proportion of decaying leaves. A single drop of such water will be found to be teeming with them. (Magnified 60 times.)

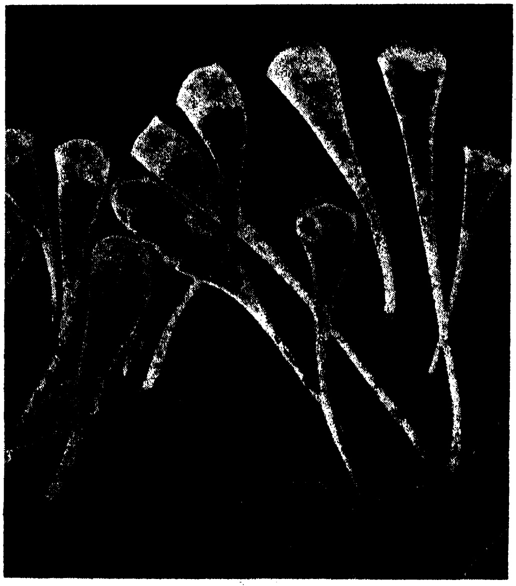


Trypanosoma lewisi, a flagellate Protozoan, parasitic in the blood of a rat. The Trypanosomes that infect man are carried by blood-sucking flies. The Sleeping Sickness of Africa is caused by a Trypanosome that lives part of its life in the Tsetse fly. The rest of its life is passed in the blood of certain game animals, especially antelope. By sucking blood first from the game animal and then from man, the Tsetse fly passes the disease on. (Magnified 1200 times.) Some idea of the menace of the Trypanosomes may be gained from the fact that over 200,000 people, out of a population of 300,000, in Uganda died from infection in six years.

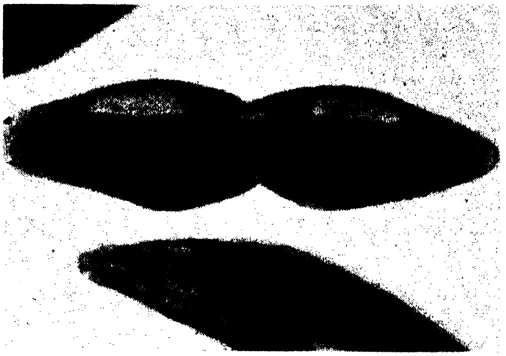
Certain of the Flagellates have taken to a life parasitic in the bodies of animals or in the sap-vessels of plants. Trypanosomes infest the blood of many vertebrates, and are carried from one animal to another by blood-sucking flies or leeches. The sleeping sickness of Africa is the result of infestation by a Trypanosome carried by the Tsetse fly. Another Flagellate, *Leishmannia*, causes the diseases known as Oriental Sore, Kala-Azar and the like. On the other hand there are many species of Flagellates living in the intestines of the higher animals, including man, without doing any harm. Indeed, they may even be beneficial. There is one outstanding example of the infection by Flagellates being not only beneficial but actually essential to the life of the animal it lives in. Termites or White Ants eat wood, but they are unable to digest it without assistance from the Flagellates. It is possible to kill the Flagellates without hurting the Termites, by placing them in a hot chamber filled with oxygen under pressure, but Termites so sterilized will die of starvation unless re-infested. Young termites are fed with partially-digested excretory matter from the parents, so their infection with these necessary Flagellates is assured. Such an arrangement is not parasitism, that is one organism living at the expense of another, but is called symbiosis, a way of life in which two things live together with mutual benefit. In this case, the Termite depends on the Flagellate to digest its food, and the Flagellate enjoys the protection afforded by the Termite's body as well as being assured of a food supply.

The Ciliophora or Ciliates are the most highly organised of all Protozoa. The one most readily obtained for examination is *Paramoecium*, the Slipper Animalcule. The body, which in shape suggests the sole of a slipper, is covered with numbers of small protoplasmic hairs, or cilia. By their rhythmic movement the animal is propelled forward in a spiral manner. Although formed of a single cell the body of *Paramoecium* is equipped with a variety of definite organs. Thus, to one side of the body there is a groove, or gullet, for the intake of food. Inside the body there is not one nucleus, as in other Protozoa, but two, a meganucleus and a micronucleus. In addition there are two contractile vacuoles as well as a string of food vacuoles: and under the entire surface, situated at right angles to it, is a layer of trichocysts, or stinging organs, weapons of offence and defence.

A second Ciliate common in ponds and streams is *Stentor*, shaped like a trumpet but with structure essentially similar to that of *Paramoecium*. The mouth of the trumpet is fringed with a conspicuous circlet of cilia which by their action produce a vortex drawing small particles of

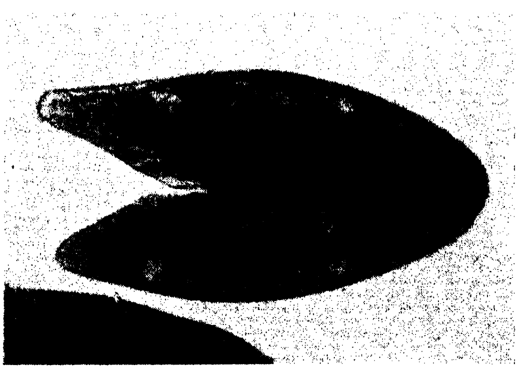


***Stentor*, the Trumpet Animalcule, one of the microscopic Infusoria living in fresh water. (Magnified 40 times.)**



Paramoecium, like all lowly forms of life, can multiply by the simple process of splitting into two. Here the process is seen in its early stages.

The division of *Paramoecium* is nearly complete.



***Paramoecium* occasionally reverses this process, when two fully-grown individuals come together and the substance of their bodies completely merges to form one.**

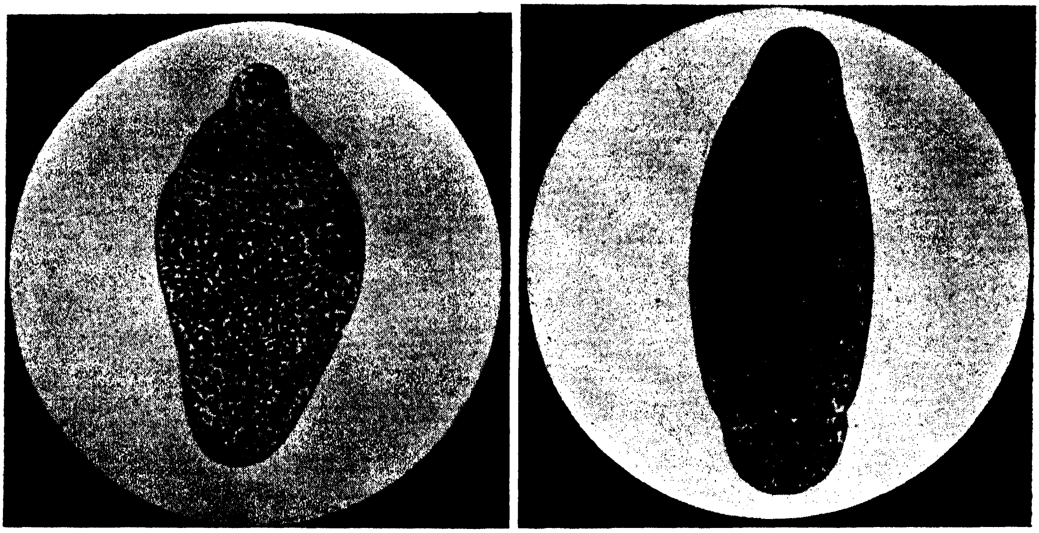
organic matter into the gullet. For the most part *Stentor* remains attached by the narrow end to the stems of water weeds, but it can release its hold and, assuming an oval shape, swim freely about. Certain species of *Stentor* have the advantage that small green unicellular plants live symbiotically within their bodies; the plant furnishes the *Stentor* with oxygen and receives in return protection and a home.

Vorticella, the Bell Animalcule, is very like a small, more rounded *Stentor* except that it is attached by a stalk several times as long as its body. From time to time the stalk contracts into the form of a coiled spring, and then slowly straightens out, pushing the bell-like body forward again. If touched, or if danger threatens it, not only does the stalk contract but the margin of the bell can be drawn in over the mouth. Some species of *Vorticella* live singly, others in groups or colonies. Although normally attached to water weeds or stones, it is not uncommon for these animals to fix themselves to the shells of water-snails, or the bodies of tadpoles and other swimming animals.

In a group known as the Suctoria, the cilia have been transformed into suckers, although in their young stages the animals have cilia. These suckers are used for capturing other Protozoa, such as *Paramoecium*, and sucking the contents of their bodies.

As with both the Rhizopoda and the Flagellates, certain species of Ciliates have adopted a parasitic life in the alimentary canal of the higher animals. One of the largest, and consequently the best for study purposes, is *Opalina*, found in the intestine of the frog. *Balantidium coli*, common to man and pig, can produce intestinal ulcers.

In the fourth class of Protozoa, the Sporozoa, parasitism has been brought to a high level, and the members of this order are all parasitic and all reproduce by means of spores. Conversely, as is usual with parasites, the body is secondarily simplified. The animal, being assured of a constant food supply and protection in the body of its host, has lost the organs, contractile and food vacuoles, so characteristic of the free-living Protozoa.

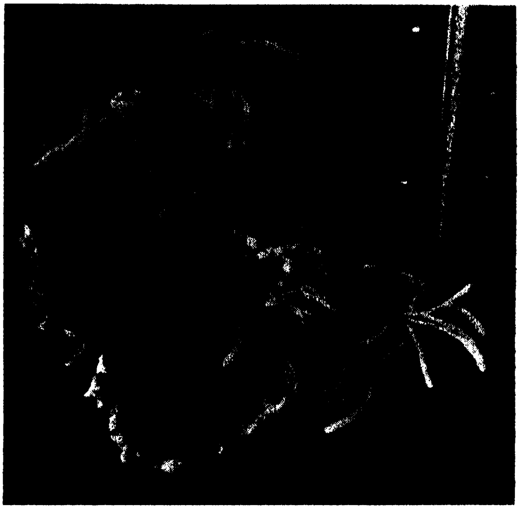


Gregarines parasitic in the intestine of a bee. (Magnified 400 times.)

Almost every species of animal has its parasitic Sporozoa, and these pass from one animal to another by means of the spores, which are seed-like bodies in which the protoplasm is protected by a tough, resistant coat. The most common are those known as Gregarines, each of which consists of two parts, the hinder part containing the nucleus. At certain times the Gregarines secrete a tough coat and undergo a number of cell divisions, followed by the fusion of the resultant cells in pairs to form spores. These are passed out in the excreta to be picked up by other animals. Since the chance of a single spore being picked up is small, the production of a large number of spores is necessary for the continuation of the species.

The best known of the Sporozoa is the Malarial Parasite, transmitted to human beings by the bite of the mosquito, in what is known as the sporozoite stage. Once inside the human body it penetrates the red blood corpuscles, becomes amoeboid and is then known as the trophozoite. In this stage it grows rapidly, almost filling the corpuscle. Then it divides into some 24 merozoites, the corpuscles break down and each merozoite attacks another corpuscle. In 48 hours, therefore, if the original infection is large, a considerable number of blood corpuscles will have been attacked and the patient develops a fever.

A mosquito sucking blood from a malarial patient takes the parasite back, which develops in the insect's stomach forming tumour-like growths on its wall. There a large number of sporozoites is formed, which later break out and become lodged in the salivary glands of the mosquito ready to be transmitted to the next person it bites.

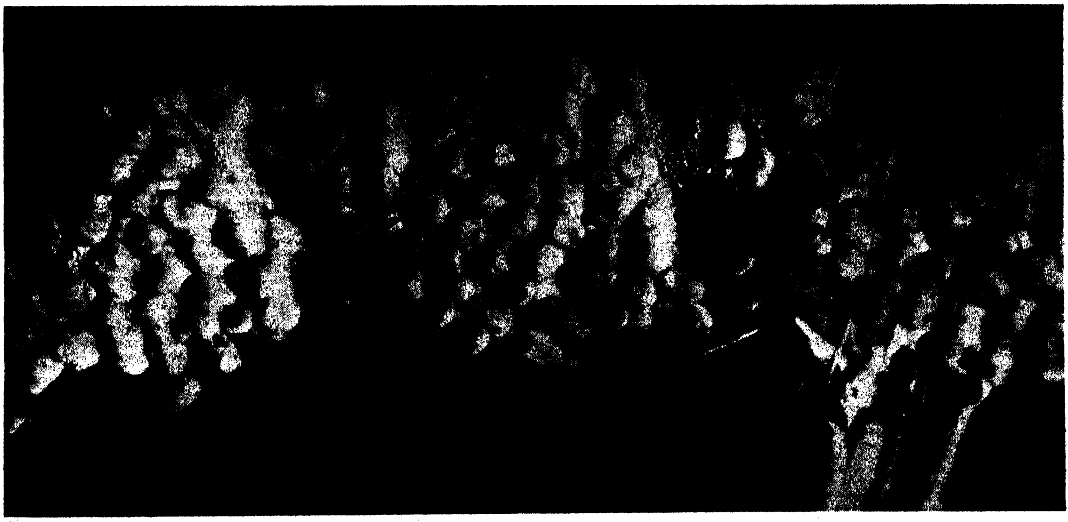


Leucosolenia blanca, the smallest sponge known, forms branched colonies. The pointed end of a pin is shown for comparison.

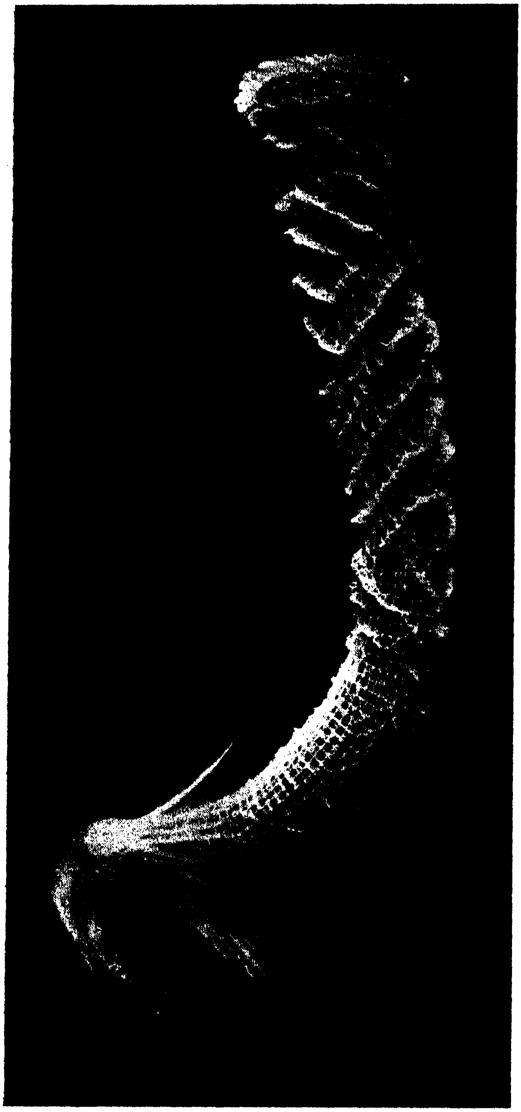
Texas fever in cattle is caused by a similar Sporozoon, in this case transmitted by a tick. In all instances, the life cycle of the Sporozoon includes a stage inside one animal and a second stage passed in the body of the blood-sucking animal preying upon it.

The Phylum Sponges

Sponges have always been a mystery. Aristotle



A section at right angles to the surface of a deep-sea siliceous sponge, showing spherical spicules just under the surface and long, rod-like spicules in the radial bundles. (Magnified 40 times.)



Euplectella aspergillum, the beautiful Venus' Flower Basket, a sponge growing in 100 fathoms off the Philippines. (One half natural size.)

2,000 years ago came to the conclusion that they were animals, but Pliny a little later decided that they were neither plant nor animal but something in between. Since those days they have been variously regarded as solidified sea foam or nests built by marine worms, while the more informed naturalists of the 18th and early 19th centuries could not make up their minds whether they were plant or animal. By 1840, however, the matter had been fairly well settled and sponges were accepted as members of the animal kingdom. This chequered history is understandable when we recall the plant-like appearance of all sponges.

The most familiar of them is of course the bath sponge, and it is this that Aristotle and Pliny doubtless saw. Although known to practically everybody, it is however only familiar to us as a dead skeleton. There are in the world several thousands of other species, of no value commercially, living in every sea from mid-tide mark down to 3,000 fathoms or more, and in every river or lake throughout the world.

The bath sponge when alive consists of a rounded purplish-brown body growing on a rock under the sea, whence it is cut by sponge-fishers. It is denuded of its flesh and the fibres of the skeleton remaining are cleaned and reach us as the article of toilet. The sponge has no sense organs and is in fact nothing more than a living hydraulic station. Scattered over the body is a very large number of microscopic pores through

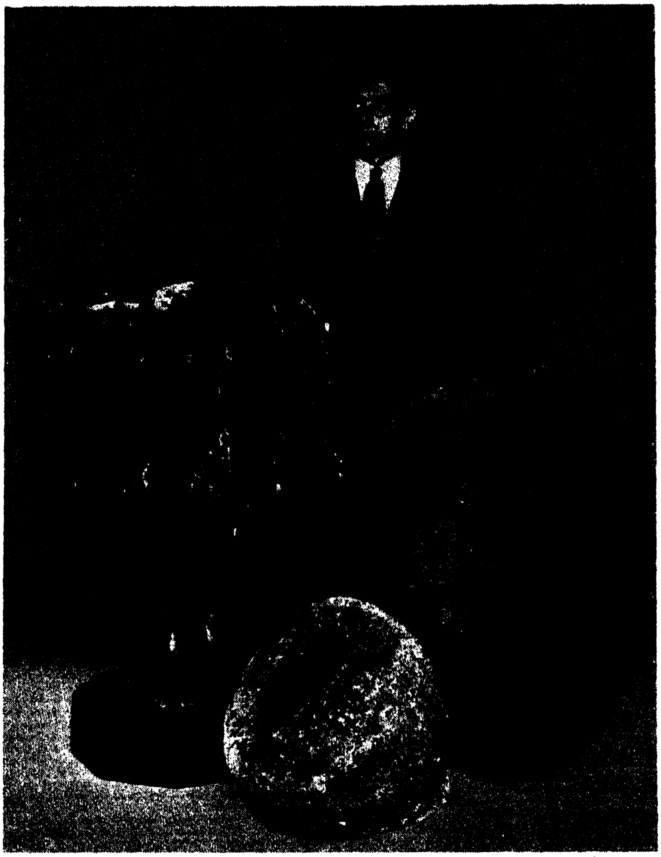
A sponge-fisher at work.

The Bath sponge is the skeleton of an animal which once lived at the bottom of the sea. It is fished up from its native haunts, cured and cleaned, and ultimately finds its way to the bathroom. Here we see a naked diver returning to the surface with a live sponge in his hand. The feats performed by the divers in search of sponges are literally breath-taking. They have been known to dive to a depth of 120 feet and remain under water for five minutes.

(Photo by Stanley Toogood.)

which water is drawn in and pumped out again through a few larger openings on the upper surface, known as the oscules. The flesh is honeycombed with a labyrinth of channels through which water passes. At intervals the smaller of these channels are dilated into rounded chambers lined with cells known as choanocytes. Each choanocyte consists of a rounded body bearing a protoplasmic collar from the base of which rises a whip-like protoplasmic thread, or flagellum. It is the rhythmic beating of the flagella which drives the water through the body and out through the oscules. In its passage the water brings to the sponge food and oxygen and carries away the waste products.

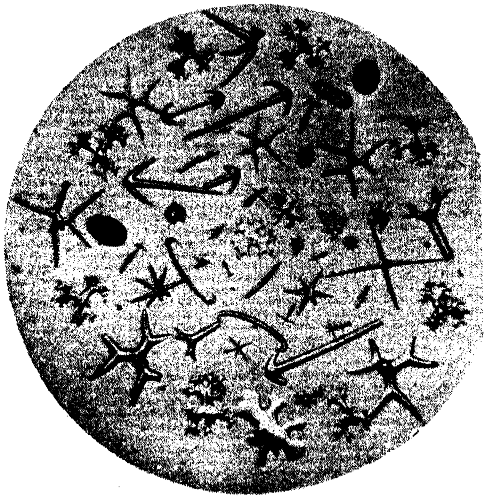
Except for those with a fibrous skeleton, like the bath sponge, the great majority have skeletons composed of separate units, or spicules, loosely knit together, made either of silica or calcite. The outward form varies considerably, from thin crusts growing on rocks or seaweeds to irregular masses, from fans and tree-like growths to cups, and so on. They may be coloured white, yellow, red, purple, brown, green and, rarely, blue.



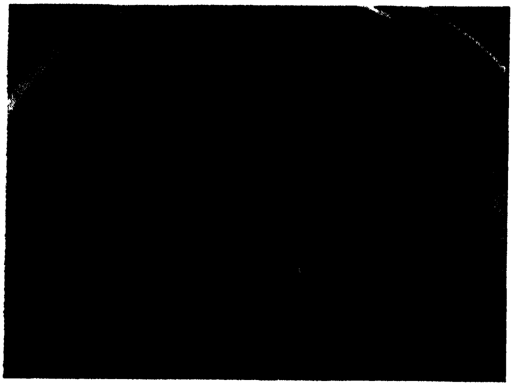
Three of the largest sponges in the world. On the left is the Neptune's Cup from Indonesia, on the right a large plate-like sponge from Australia, and in the centre the Loggerhead Sponge from the Gulf of Mexico.

Probably all sponges are hermaphrodite, the sperms being shed into the water and carried into another sponge in the water currents. There the eggs are fertilised and continue their development *in situ*. Ciliated larvae escape into the sea, swim about for some twenty-four hours, settle down and undergo metamorphosis into young sponges, minute crusts, very difficult to see.

Although sponges reproduce sexually it seems that they multiply more commonly asexually or



A selection of spicules from different siliceous sponges to show the great variety of shape. (Magnified 100 times.)



Regenerative cell masses formed by the cells of a sponge after having been squeezed through fine silk. (Natural size.)

vegetatively, either by budding or by some form of fragmentation. In some species it is more marked and cases are known where new sponges are formed by automatic splitting up of the parent body.

Freshwater sponges have a specialised asexual reproduction, by the formation of gemmules. These are spherical and consist of a double coat of chitin containing a shapeless mass of cells and even though the rivers or lakes freeze or dry up the contents of the gemmules are unaffected. There is an obvious advantage to the freshwater species in this. Indeed it is doubtful whether sponges, and other freshwater animals like the Polyzoa (see Chapter 11), would have been able to populate the rivers and lakes had they not evolved such a method of reproduction.

Freshwater sponges are usually green but may be pale yellow if growing in places where they are sheltered from daylight. This resemblance to plants, together with the seed-like appearance of the gemmules, gave one of the strongest arguments in favour of the theory that sponges are in fact plants. The green colour is due to the presence of unicellular plants living in the sponge tissues. This is a kind of mutualism or symbiosis, where two organisms live together in such a way that both benefit (see Chapter 14). In this case the plants receive a lodgement in the body of the sponge and the sponges benefit by feeding upon some of the plants.

The method of feeding of sponges is still not known for certain. It is suspected that they feed either upon decaying organic matter in the form of small particles or on bacteria. At all events they grow best in water impregnated with rotting matter.

Sponges may be readily found on almost any part of the coast except where it is very sandy, but these are usually of small size and irregular shape. The more symmetrical forms are found in the deeper waters and the most beautiful of all are found in the very deep waters of 100 fathoms or more.

Sponges of commerce grow only in the warmer seas and are almost entirely confined to the Mediterranean and the Gulf of Mexico. In the former, sponge-fishing has been going on since the days of the Ancient Greeks, or even earlier, and until comparatively recently the only method has been by naked divers. In modern

A branching mass of the green freshwater sponge, *Ephydatia fluviatilis.*

times, however, machine divers have been used as well as the dredge, in the deeper water, but in some places harpoons with re-curved prongs on handles twenty feet long are used, operated from a dinghy, the sponges being hooked and brought to the surface.

The sponge fishery of the Gulf of Mexico which is centred mainly around the Bahamas and the Coast of Florida was started in 1841 by Greeks, and the Greek methods of fishing are largely used. In the last 40 to 50 years attempts have been made to grow sponges in farms, taking advantage of the fact that they can be cut to pieces and each piece will grow into a new sponge. The idea was to plant these pieces each attached to a flat stone in rows on the sea bed. In theory it is possible, but the practical difficulties are many. Some 12 years ago experiments had reached the point where farming seemed likely to start on a commercial scale, when a mysterious disease struck the West Indian sponges and almost wiped them out. Some farms have been established, however, on the coast of Florida.

NEW BODIES FOR OLD

REGENERATION IN THE ANIMAL KINGDOM

Regeneration, the ability to replace lost parts, is most strongly present in the lower, less specialised animals, and is progressively lost as we ascend the animal scale until in the higher vertebrates it amounts to no more than the healing of wounds. In sponges, the lowest Metazoa, it reaches its highest expression. Here, the body can be broken up and each fragment is capable of growing into a new sponge. It is even possible to separate all the cells of the body, by passing the tissues through fine silk: a process known as dissociation. Yet the cells will come together again, after a free and independent existence lasting a few hours, to form new sponges. This process, known as dissociation and regeneration, has been observed in the laboratory in sponges and some of the Coelenterata, as well as in the Protochordata, the forerunners of the vertebrates. It is also made use of by these animals under natural conditions.

Four specimens of a sponge known as the Sea-orange (*Tethya aurantium*), which reproduces almost entirely by small, rounded buds formed on the surface. (Natural size.)

After the Sponges and Coelenterates, and with the exception of the Protochordates, this power of wholesale re-growth is progressively lost, the loss being correlated with the increasing organisation of a central nervous system. Certain of the Flatworms (Platyhelminthes) can be cut into a dozen pieces or more and each piece will grow into a perfect but small worm, in every respect similar to the parent body from which it was cut. When we come to the Bristle-worms (Annelida) with their more highly-organised central nervous system, regeneration is limited. An earthworm, for example, if cut into two will, under certain conditions, grow into two worms, the front half growing a new tail and the hinder end growing a new head.

This regeneration is closely associated with the process of asexual reproduction, and is best described in the words of Dr. Th. Mortensen of Copenhagen: "A very characteristic property of Echinoderms is their strong power of regeneration. To break an arm, or all its arms, means nothing for a brittle-star—they simply grow out again. A sea-lily, when feeling uncomfortable, may throw off not only its arms, but also the whole disc, containing the intestinal canal and other organs, to regenerate it all again. Similarly many sea-cucumbers may throw out their whole intestine, to form it again; the same obtains very freely in many brittle-stars, a

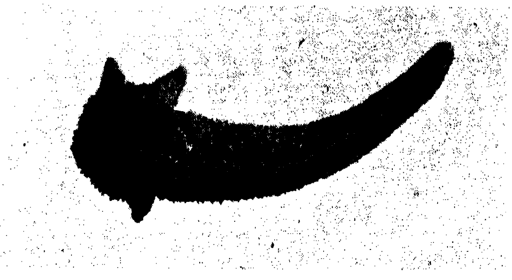
The brittle-star *Ophiactis savigni* multiplies by breaking into two. This strong regenerative power is also seen in the ability of other brittle-stars to re-grow lost arms. The group of brittle-stars *(Ophiopholis aculeata)* shown here have some of their arms either damaged or regenerated, the regenerated portion being thinner and, at first, lighter in colour.

rather enviable property, to be able to throw away its stomach, genital organs, etc. if unsatisfactory and make fresh good ones."

"This power of regeneration is made use of in propagation by several forms of Echinoderms. Some species of sea-cucumbers divide themselves into two parts, the fore-end reproducing a new posterior end, and similarly the posterior end forming a new anterior end. A sea-star common in the Indo-Pacific region, *Luidia unilifera*, throws off deliberately some of its arms, or pieces of them, and each piece grows out to a new sea-star, all stages of regeneration being quite commonly met with on the coral reefs, where this sea-urchin lives. Several other sea-stars, and likewise a number of species of brittle-stars, divide themselves into two halves, each half regenerating the lacking half of the disc and arms. Some of these self-dividing species propagate almost exclusively in this way, propagation by means of sexual products being quite exceptional. A very curious case was observed by the present author in the West Indies. In a certain locality one of the self-dividing brittle-stars *Ophiactis savigni* occurred in great numbers, but all of them were males. The place evidently had originally been colonized by a single male specimen, having gone in there as a pelagic larva. This specimen had gone on dividing and dividing, forming thus a whole population—a real male community."

The remaining invertebrates have very largely lost this power. Among the Mollusca it is confined almost entirely to the ability to repair a broken shell, and in the Arthropods (Crustacea, Spiders, etc.) to the replacement of lost limbs. In the Vertebrates, fishes have a limited power of repairing damaged fins, certain amphibia, such as newts, can grow a new leg, and some of the lizards can voluntarily throw off the tail and grow a new one.

The story of reproduction by regeneration given above by Dr. Mortensen shows how closely these two processes are connected. The splitting of a single Amoeba into two, with the formation of two individuals, is not only a process of reproduction; it also involves regeneration. Sponges also can reproduce by regenerative cell masses, or by splitting into fragments. In other words, just as the gardener multiplies his plants by taking cuttings of them, so many of the lower animals are able to take cuttings of themselves.



The so-called Comet-form of a starfish. All but one arm has been lost, and of the four lost, three can be seen starting to grow again.

CHAPTER VIII

PHYLUM COELENTERATA

Diploblastic animals armed with nematocysts, or stinging-cells

DIPLOBLASTIC AND TRIPLOBLASTIC ANIMALS

THE Coelenterata include such diverse forms as the tiny freshwater hydra, the moss-like sea-firs, the fragile jelly-fish and sea-anemones, and the stony corals. Although so different in appearance and habits, all have fundamentally the same structure. Furthermore, they have two things in common which distinguish them sharply from the rest of the Animal Kingdom. Firstly, the body is a simple sac, with an opening at one end only, the walls of which consist of two layers of tissue, an outer ectoderm, and an inner endoderm. Between is a structureless layer, or mesogloea, but as this is not a tissue in the accepted sense of the word, we speak of the Coelenterates as being two-layered, or diploblastic. This is the fundamental difference between the Coelenterates and the rest of the animals we have to consider because in the latter, whether worm, crab, insect, reptile or ape, the body is built up from three primary layers; an outer ectoderm, which gives rise to the skin and all associated organs such as bristles, scales, hair or nails, a middle layer, or mesoderm, from which is derived the muscles and most of the internal organs, and an inner layer, or endoderm, which lines the gut. In the Coelenterates, the two layers of tissue are obvious throughout life, but in the triploblastic animals, the three layers of tissue are usually only to be recognised in the embryo, since they are early obscured by the multiplicity and complexity of the organs to which they give rise.

NEMATOCYSTS, STINGING- OR NETTLE-CELLS

The second thing distinguishing the Coelenterates from all other animals is their possession of stinging- or nettle-cells, as they are often called, from their resemblance to the stinging hairs of nettles. Although all Coelenterates, except the Ctenophora, have them they are best known in the jelly-fish, which most people carefully avoid. Certainly the sting of some jelly-fish can be

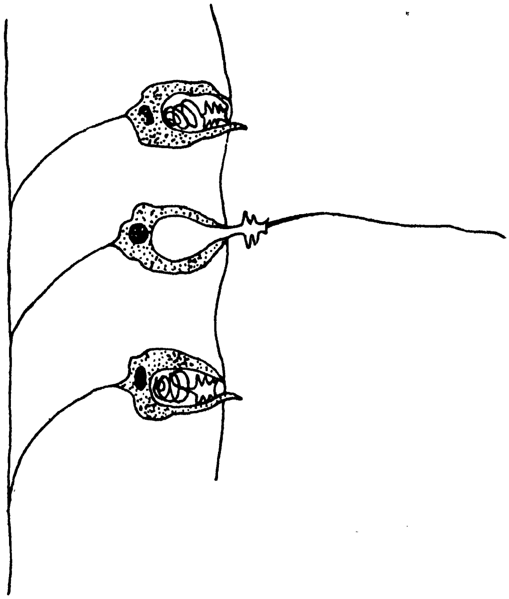
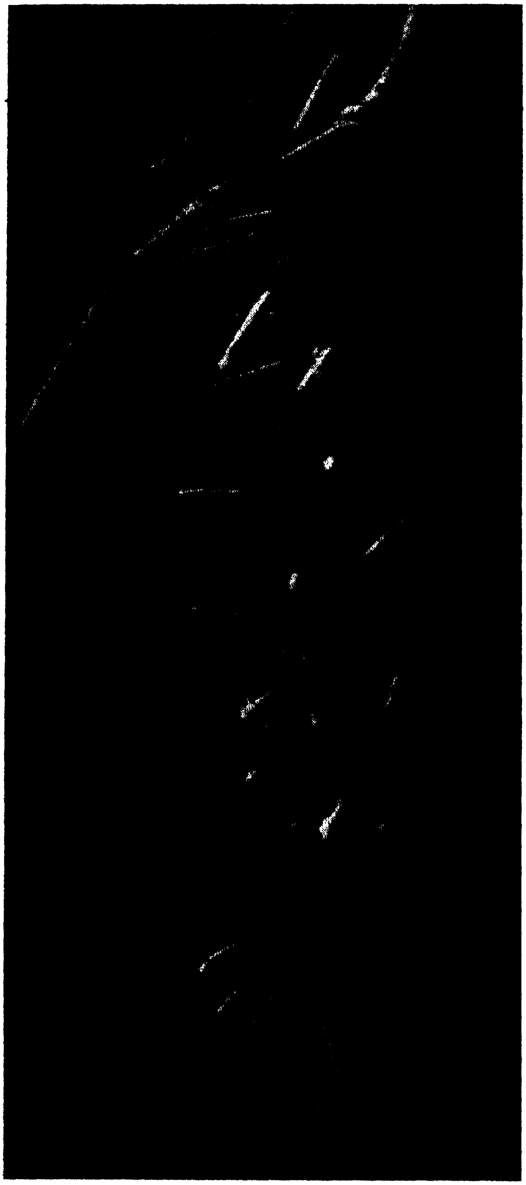


Diagram showing three nematocysts in the body wall of one of the Coelenterates. In the middle one the thread has been shot out, showing a group of barbs at its base. Each nematocyst is connected by a nerve fibril to the network of nerve-cells in the middle layer of the wall.

extremely unpleasant; that of some tropical species has often proved fatal.

Stinging cells, or nematocysts, usually microscopic in size, are distributed over the whole surface of the jelly-fish, but more particularly on the tentacles surrounding the mouth. Each consists of a capsule, filled with poison, and with a long hollow thread coiled up inside. The capsule is buried in one of the cells of the skin, which bears a short spine on its outer surface. When touched this spine contracts and causes the coiled thread to be shot out with considerable force, piercing the skin of whatever has touched it. Then the poison starts to flow down the tube. If it is a small animal that has touched the jelly-fish the poison will enter its body and paralyse it, even killing it. Large animals so stung can, of course, escape. But in doing so they wrench the capsules of the stinging cells out. If stung on the hand, we should find that the threads of the stinging cells had entered and become firmly embedded in our skin, but the capsules, containing the poison, remain on the surface and can be broken off and removed when sand is rubbed over the skin. But rubbing with sand can obviously only be effective if done quickly, before the capsules have emptied themselves of poison.



Clava squamata, one of the Sea Mosses. Each stem of this Hydroid comprises a colony of Hydra-like polyps. (Magnified 100 times.)

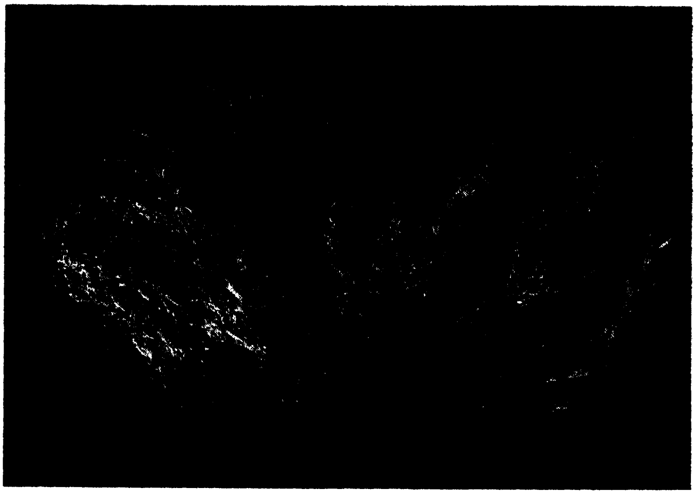
The presence of stinging cells can be demonstrated in another way, by passing the finger gently over a sea-anemone when the tentacles will cling slightly to it. This is because the threads of scores of stinging cells have been shot into the skin, delaying, by a minute fraction of a second, the movement of the finger, but the sting of the ordinary sea-anemone is quite harmless to human beings.

Like the jelly-fish, sea-anemones, corals and the other animals related to them are, despite their sedentary habit and inoffensive appearance, their entrancing colours and fascinating shapes, nothing better than submarine fortresses bristling with lethal batteries, a constant menace to the many small creatures moving around them.

THE ALTERNATION OF GENERATIONS

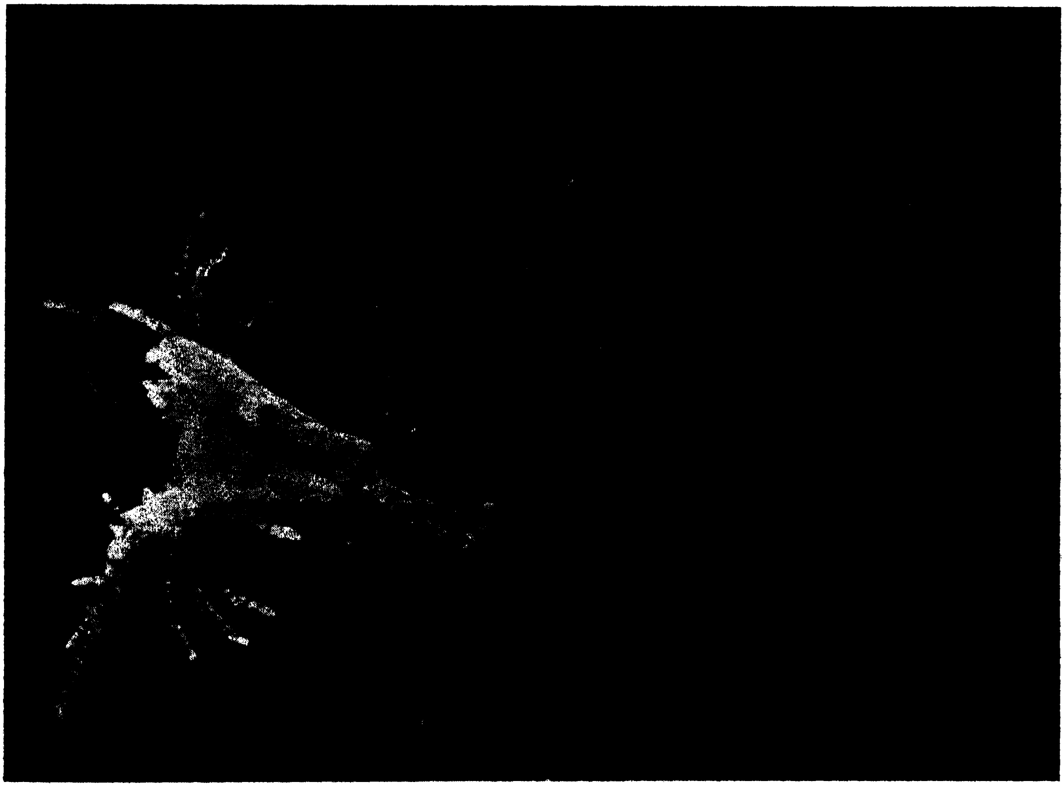
Why, if they are related to each, are a sea-anemone and a jelly-fish, or a coral, or the simple Hydra so different in appearance? To answer this we must understand the phenomenon known as the alternation of generations, commonly met with among plants, but rare among animals.

Of the many things found growing on the rocks at low tide, which might be readily mistaken for small sea-weeds, are the Sea-firs. Typical



A fine colony of *Sertularia*, composed of a tangle of branches such as are shown on p. 152. (One half natural size.)

examples are *Sertularia* and *Obelia*. Each stem and its branches is composed of a number of joints arranged in a zigzag fashion, each ending in a cup containing a small polyp, like a delicate flower, capable of being expanded beyond the rim of the cup or of being withdrawn completely into it. This colony of polyps began life as an oval larva, swimming about freely for a while and, finally, settling on the surface of a stone to which it became fixed at one end. Then came a transformation, a metamorphosis. At the free end of the larva a round hole appeared, and, surrounding this mouth, a ring of tentacles. This, the young polyp, then secreted around itself a coat of a tough substance, like a very thin coating of horn. In a short while a blister

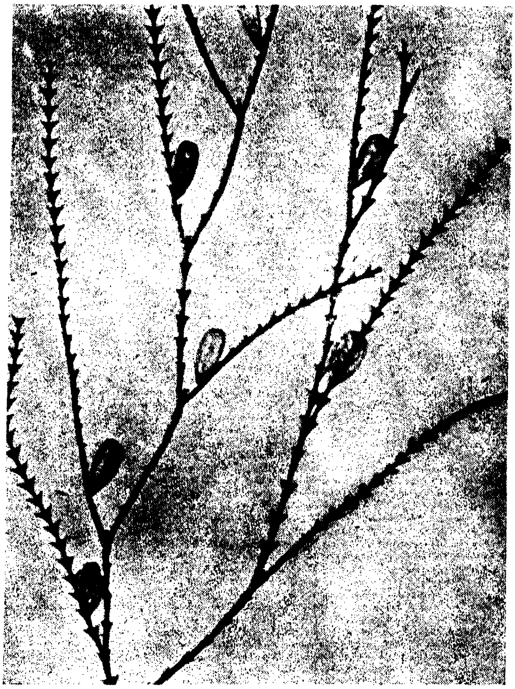


A portion of a colony of *Obelia*. The vase-shaped gonothecae contain the blastostyle from which the tiny jelly-fish of the medusoid generation are budded off. (Magnified 200 times.)

(By Courtesy of G. B. Instructional Ltd.)

appeared on one side of the tube, which grew in size until it was as big as the polyp itself. This was a bud growing out from the original polyp. From this bud grew out another. First one way, then the other, the buds appear in rapid succession, building up the zigzag stem.

While this stem is developing, growth is taking place in another way. From the base of the original polyp, tubular, root-like threads grow out over the surface of the stone, and, at intervals, fresh stems arise by a similar process of growth to that described for the first stem. And so the bushy tangle, known as the sea-fir, is formed.



The dried stem of another Sea-fir *(Sertularia)*, shows clearly the succession of cups holding the polyps, and the vase-like gonothecae. (Magnified 40 times.)

Each polyp, in its horny cup, is nothing more than a small fleshy bag, the wall of which is composed of two layers of cells with a thin layer of mesogloea between, with a mouth at one end surrounded by a ring of slender tentacles, each polyp being joined to its neighbour, so that the thousands of polyps in a colony of *Sertularia* are all in protoplasmic continuation with each other.

After a while, to this purely vegetative growth, represented by the budding of new polyps, is added a new kind of growth. A different kind of cup appears at intervals on the stems. These are goblet- or urn-shaped. At the centre of each of these is a fleshy rod, and on this small warts appear, which later become saucer-shaped and eventually drop off and float out into the sea. Seen under the microscope, these saucers prove to be minute jelly-fish. Their life is comparatively short, but before death they shed numerous eggs into the sea, which develop into round or oval larvae.

Sertularia has two methods of growth, the plant-like budding and stem formation, which constitutes the vegatative or hydroid generation; and the free-swimming jelly-fish, or medusa, which lays eggs, which is the medusoid generation. And the life history of *Sertularia operculata* is a series of alternations of the hydroid and medusoid generations.

The phylum Coelenterata is divided into:

Order Hydrozoa (Hydra and zoon: Hydra-like animals), including the sea-firs, Portuguese Man-o'-war, and the freshwater *Hydra*.

Order Scyphozoa (Scyphos = cup, zoon = animal), the true jelly-fish.

Order Anthozoa (Antho = flower, zoon = animal), including sea-anemones, sea-pens, sea-fans, precious and stony corals.

Order Ctenophora (Ctenos = a comb, phora = to carry) the comb-jellies. Although included in the Coelenterata, these have no nematocysts.

In the Hydrozoa, both hydroid and medusoid generations are represented but the hydroid generation is the most important and the most obvious; in the Scyphozoa, the medusoid generation is the most important, the hydroid generation being almost completely suppressed; and in the Anthozoa, only the hydroid generation is known, but the polyps of this order are so like those of the Hydrozoa, as to leave no doubt regarding their relationship to them.

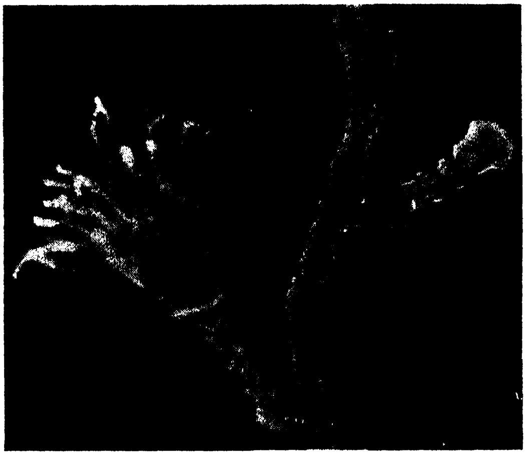
Order Hydrozoa

Having considered the structure of the polyps of the Hydrozoa, we can examine their behaviour. Each polyp feeds itself, but since all polyps are in protoplasmic continuity it is probable that food may be passed from one to another. Here is a distinct division of labour. In each colony there are two kinds of polyps: the nutritive polyps, and the reproductive polyps—those in the urn-shaped cups which bud off medusae. The nutritive polyps have no other function than to feed. This they do by emerging from their protective cups, expanding their tentacles, and gently waving them about in the surrounding water. They have no other power of movement, and no sense organs other than isolated nerve-cells scattered between the cells of the ectoderm. They must, therefore, wait until some small creature swimming in the sea comes close enough to touch the tentacles. Immediately the stinging-cells are stimulated and the victim is poisoned and held by them. Then a sympathetic response is seen in the tentacles. They all begin to close in towards the mouth, carrying the victim to it and pushing it in.

Inside the cavity of the bag-like body of the polyp, the gastric cavity, the presence of food stimulates the inner layer of cells, the endoderm to pour out digestive juices. When digestion is finished the undigested portions are rejected through the mouth.

Not all the Hydrozoa are sedentary. In *Diphyes* two of the polyps have lost their tentacles and have developed into inverted bells, acting as floats to the rest of the colony, which consists of nutritive and reproductive polyps attached to the slender stem hanging down from the floating bells. *Physophora* has two rows of such swimming bells, and the rest of the polyps are grouped immediately beneath, with long stinging tentacles trailing in the sea ready to seize whatever may come in contact with them. And in *Physalia* the swimming bells are replaced by a large bladder, filled with gas, which floats on the surface, and underneath are grouped large, flask-shaped nutritive polyps bearing tentacles heavily charged with stinging-cells. But whereas *Diphyes* and *Physophora* move about by the aid of rhythmic contractions of the swimming bells, *Physalia* floats on the surface of the sea and is gently borne along by the wind.

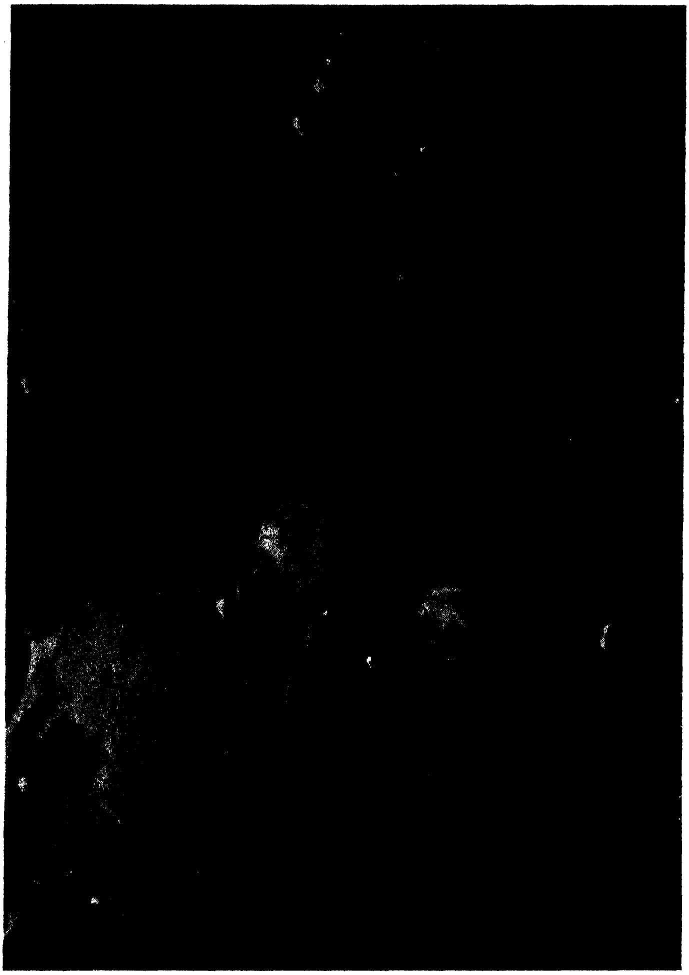
A medusa or jelly-fish, showing the tentacles hanging down from the centre of the umbrella-shaped body. Jelly-fish drift with the currents and may often be seen at sea in thousands.



A portion of the stem of *Obelia*, one of the Sea-firs, with a well-developed flower-like polyp on the left and a budding polyp on the right. The transparent tube, or perisarc, surrounds the living stem, and forms a cup into which the polyp can withdraw. (Magnified 150 times.) *(By Courtesy of G. B. Instructional Ltd.)*

Order Scyphozoa, or true jelly-fish

A typical jelly-fish is umbrella-shaped, with the upper surface smooth and even, and with all the essential organs situated along the margin of the umbrella or on the undersurface. It is essentially nothing more than a free-swimming polyp in which the anatomy has become very much complicated. To begin with, the gelatinous mesogloea of the hydroid polyp has become much enlarged and spongy, and its interstices filled with fluid. In fact, the body of a jelly-fish



The medusoid stage of the Scyphistoma (or Jelly-fishes proper) alternates with a hydroid stage, seen here. (Magnified 20 times.)
(By Courtesy of G. B. Instructional Ltd.)

consists of 99 per cent. water. The edge of the umbrella is fringed with a row of small marginal tentacles, and the corners of the mouth, which is situated in the centre of the undersurface of the body, are drawn out into four, or more, large fleshy tentacles, heavily armed with stinging cells. The reproductive cells are on the undersurface of the body also.

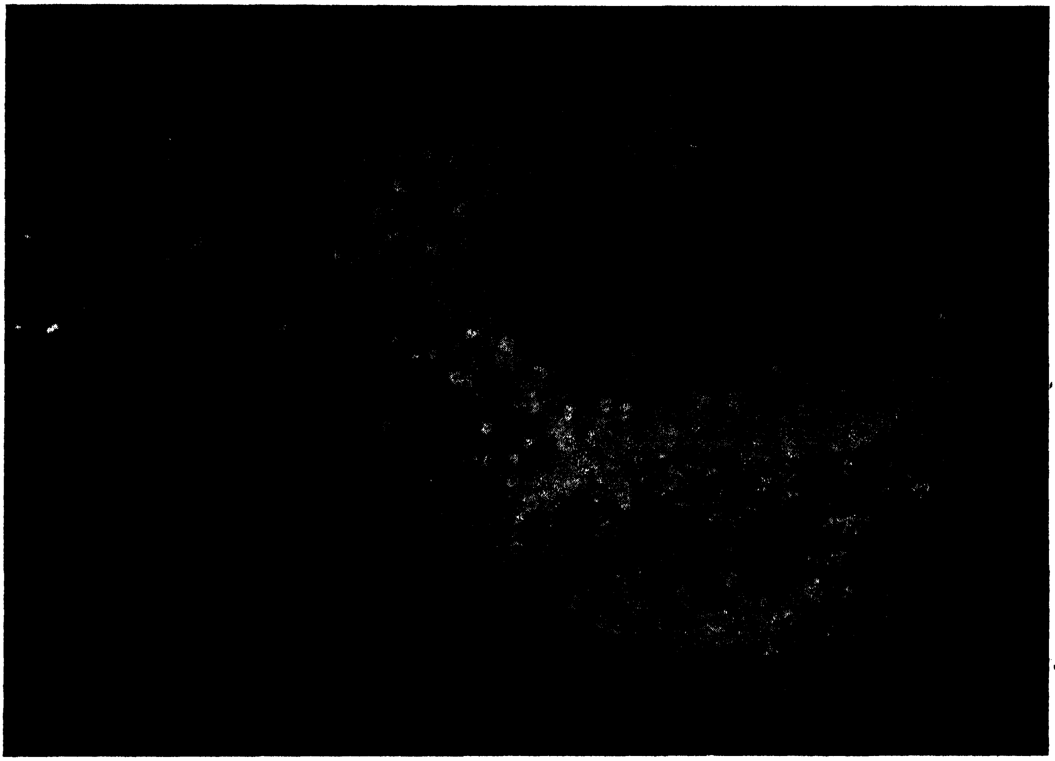
At regular intervals along the edge of the umbrella are sense-organs, simple in construction, serving in all probability as balancing organs, although they may also be sensitive to light. The behaviour of the jelly-fish, however, depends very largely on external circumstances; the varying conditions of the water, light and other factors determining to a large degree the activity of the animal. The fact that jelly-fish are found in shoals does not mean that they have gregarious or social instincts. The enormous shoals of jelly-fish are brought together by the action of currents, in exactly the same way as shoals of cuttle-bone, driftwood, and other inanimate objects may be found in the sea. The method of multiplying is simple in the extreme, as in all the lower animals we have so far considered. When the reproductive organs are ripe, their contents, ova and spermatozoa, are shed into the sea where fertilization takes place. The fertilized egg develops into a hollow, ciliated larva, which swims about for a while before sinking to the bottom, and attaching itself by one end to a stone or rock. Then, at the free end, a mouth appears, which is soon surrounded by a ring of tentacles. This is the scyphistoma, representing the hydroid generation, of the jelly-fish, and bears a close resemblance to the nutritive polyp of *Sertularia*. But instead of budding laterally it buds transversely. Soon after the first ring of tentacles is formed a second ring appears immediately below it. Meanwhile, the body becomes constricted between the two rings. Then a third and fourth ring of tentacles appear, and so on, until the scyphistoma, now about 1 cm. high, is marked with a series of rings of tentacles, with the body constricted between each ring, so that ultimately it comes to resemble a pile of saucers with fringed margins. Each saucer in turn, starting from the top, begins by muscular movement to wrench itself free and swim away to grow into the familiar jelly-fish.

As has been said, a typical jelly-fish is umbrella-shaped, but not all have this shape. Some are helmet-shaped, some almost globular, others cuboid; but all agree closely in construction except that the mouth-tentacles may be short or long, few or many, simple or complicated. All are marine except one, *Craspidacusta*, which lives in lakes and rivers. A few, like *Pelagia noctiluca*, are phosphorescent. With a few exceptions they are free-swimming.

Order Anthozoa (sea-anemones, sea-fans, sea-pens, precious and stony corals)

The polyps of the Anthozoa have a similar form to that of the hydroids, but there is one important difference. The gastric cavity, instead of being simple, is subdivided into compartments by vertical mesenteries, and is reached from the mouth through a tubular gullet. They are almost exclusively marine, a few only living in brackish water, and none in freshwater. There are no special sense-organs, and reproduction is by ciliated larvae developing direct from the fertilised egg. All are sedentary; but one anemone, *Minyas*, has the base of the body converted into an air-chamber, which enables the animal to swim freely at the surface of the sea.

The sea-anemones are familiar to most people so far as external appearance is concerned, since so many of them grow well inshore and may be seen when the tide has gone out; but a less familiar but much more interesting feature is their method of reproduction by fragmentation. Sea-anemones, it would appear, are less bound by rules than are most marine animals. Variety would appear to be the hall-mark of their behaviour. Thus, although some species tend to stay indefinitely in one spot provided circumstances are favourable, most move about readily should occasion demand, and some are seldom still. The method of locomotion is varied. The commonest is brought about by movements of the basal disc similar to those seen in the foot of a snail. A few species drag themselves along by



Dead Man's Fingers *(Alcyonium digitatum)* may be seen as pink masses growing on rocks or pier-piles, or cast up on shore by storms. Here it is seen under water with the beautiful flower-like polyps expanded. (Natural size.)
(Photo by Douglas P. Wilson.)

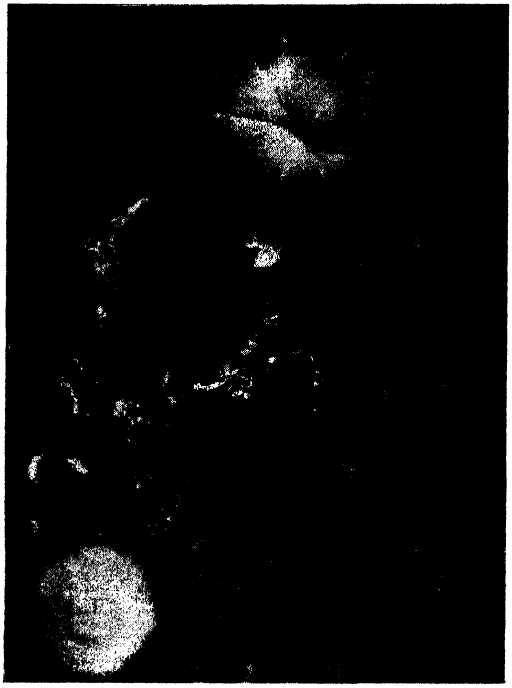
Sea-pens are composed of a central stem, with the base embedded in the mud, and the pinnules bearing numerous polyps. (One-tenth natural size.)
(By Courtesy of G. B. Instructional Ltd.)

means of ridges running along the sides of the body. Some let go their hold on the substratum, inflate the body and are carried about by the currents. Others, using a similar method, float head downwards at the surface. Some walk on their tentacles; others progress by movements strongly reminiscent of jumping; and in a few species, by lashing movements of the tentacles, a close approximation is made to swimming.

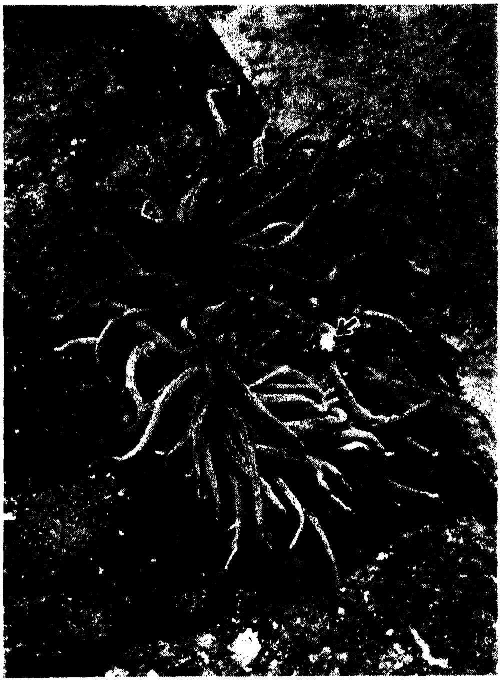
These descriptions of the various methods of locomotion build a markedly different picture to the one normally presented to our minds by seeing the sea-anemones at rest or only faintly active on the beach at low tide, or even by those fully submerged, and, therefore, more active, in rock-pools. But it is possible for anyone to test at least some of these things at first hand. We may select a rock-pool and, as the tide is receding, gather a number of anemones, place them in a pool, close together, and leave them. When first deposited they will fix themselves in the positions in which they were placed; but if the pool is again visited, several hours later, as the tide is coming in, the anemones will probably be found to have dispersed themselves evenly over the floor of the pool. Or, to carry the experiment further, if a large pool be selected such as will be little disturbed by the incoming tide, and a number of anemones put into it and left till the following day, the anemones will, in all probability, have departed leaving the pool with its original inhabitants only.

The variety shown in the methods of locomotion is equalled by the many and strange ways in which anemones will reproduce themselves, First of all, there is the usual sexual method of

A group of large sea-anemones with their tentacles waving about to trap small shrimps or fish that venture within reach.



A group of sea-anemones from just below low-tide mark.

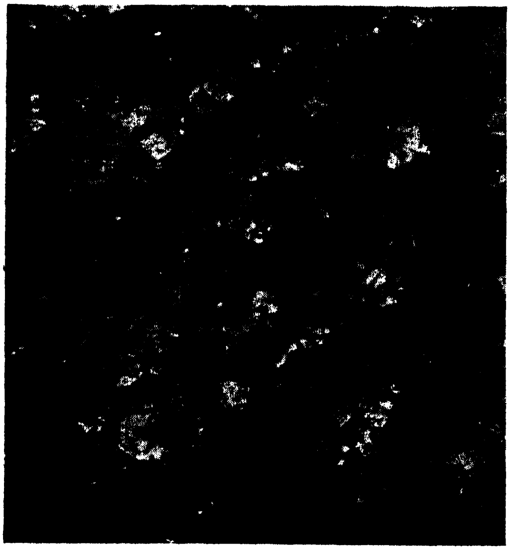


A Sea-anemone in the act of feeding.
When this photograph was taken a piece of food had fallen on to one of the tentacles of a sea-anemone (see arrow) and had stimulated all the tentacles into movement so that they looked like a writhing mass of snakes. When food, whether it be a live animal or a piece of dead flesh, touches a tentacle, the nematocysts lay hold of it and the tentacle automatically begins to curl over towards the mouth, seen here in the centre of the picture. The movement is communicated to the rest of the tentacles, which begin to writhe in a searching movement, as if to aid the one tentacle by laying hold of the food. The tentacles ultimately all bend in towards the mouth and push the food into it. Feeding is purely mechanical, an automatic response to the capture of food, and an anemone will continue to feed even after its stomach is full. If it becomes uncomfortably gorged, the food is vomited forth and the feeding process starts all over again.

A sea-fan, or soft coral, from the West Indies.

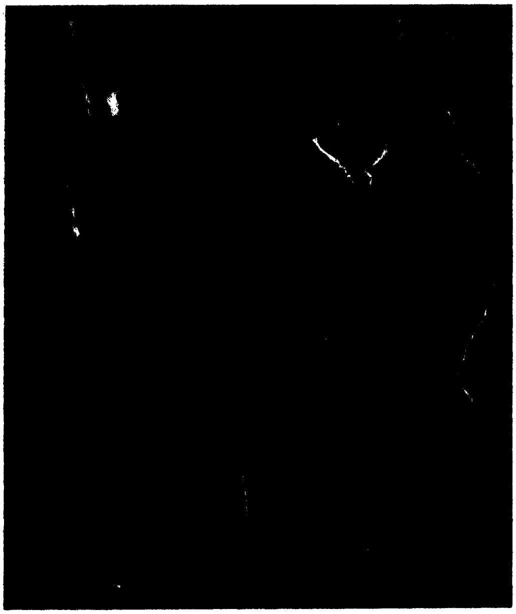
multiplication. Sea-anemones are hermaphrodite and will produce either ova or spermatozoa, sometimes both together. The ova may, like the spermatozoa, be shed into the sea, to take their chance, or they may be fertilised and the larvae mature fully inside the parent body. Some species have a breeding season, others breed all the year round. In addition to the sexual method, there are several forms of asexual reproduction. Some anemones split longitudinally, producing two perfect individuals where there was previously one. Others split transversely, the splitting being preceded by the growth of a ring of tentacles from the body wall just below the line of rupture. In some species young individuals bud off from the edge of the parent, and cases are known of sea-anemones which, in moving about, leave pieces of their basal discs behind, each piece growing into a new anemone.

With such ability to reproduce themselves, sea-anemones would become an overwhelming pest had they not numerous enemies. First among these are the Nudibranchs, shell-less molluscs, known as sea-slugs. One of these, particularly, an animal of some 2 inches in length and of a



A group of sea-anemones after the tide has receded. The tentacles are withdrawn completely, each animal looking like a lump of reddish jelly.

bright yellow colour, readily recognisable by its slug-like appearance, but difficult to see because it harmonises so well with its surroundings, may commonly be found on the shore under seaweeds or on the rocks, as often as not browsing on either sponges or anemones. Sea-slugs must have the most hardy digestive organs. They are equally undisturbed whether feeding upon the tissues of sponges filled with calcareous or siliceous needles, or the tissues of anemones armed with stinging cells. Other enemies are starfish, fishes of many different species, such as whiting, haddock, and some of the flatfish, and the Pycnogonida, or sea-spiders, which may, not infrequently, be found at low-tide level. Cannibalism, moreover, may not be excluded as one of the causes of death; small or weakly anemones may be devoured by their neighbours. Yet, in spite of the many hazards, some anemones attain a great age. There is a fully-authenticated record of one group having lived in captivity for nearly a hundred years.



A group of Comb-jellies or Sea Gooseberries (Ctenophora) swimming. In some the tentacles can be seen trailing, in others they are withdrawn. The comb-like plates of cilia are arranged in longitudinal rows on the surface of the transparent body. (Twice natural size.)
(Photo by Douglas P. Wilson.)

Order Ctenophora (Comb-bearers)

The Comb-bearers or Sea-gooseberries are difficult to classify. Although superficially like jelly-fishes they have no nematocysts, nor do they move with pulsations of the body. They may be egg-shaped, spherical, or, as the beautiful Venus' Girdle, ribbon-shaped. They often occur in shoals, swimming near the surface, transparent, gelatinous, iridescent in the sunlight, luminescent in the dark. Each one bears a pair of long tentacles armed with numerous small suckers, or lasso-cells, with which food is captured. In addition, each has eight crescent-shaped bands running lengthwise down the body along which are set rows of comb-like plates fringed with cilia, acting as paddles to propel the animal through the water.

At one end of the body is a mouth leading into a gullet, and thence into the stomach, from which arise a number of digestive canals ending blindly.

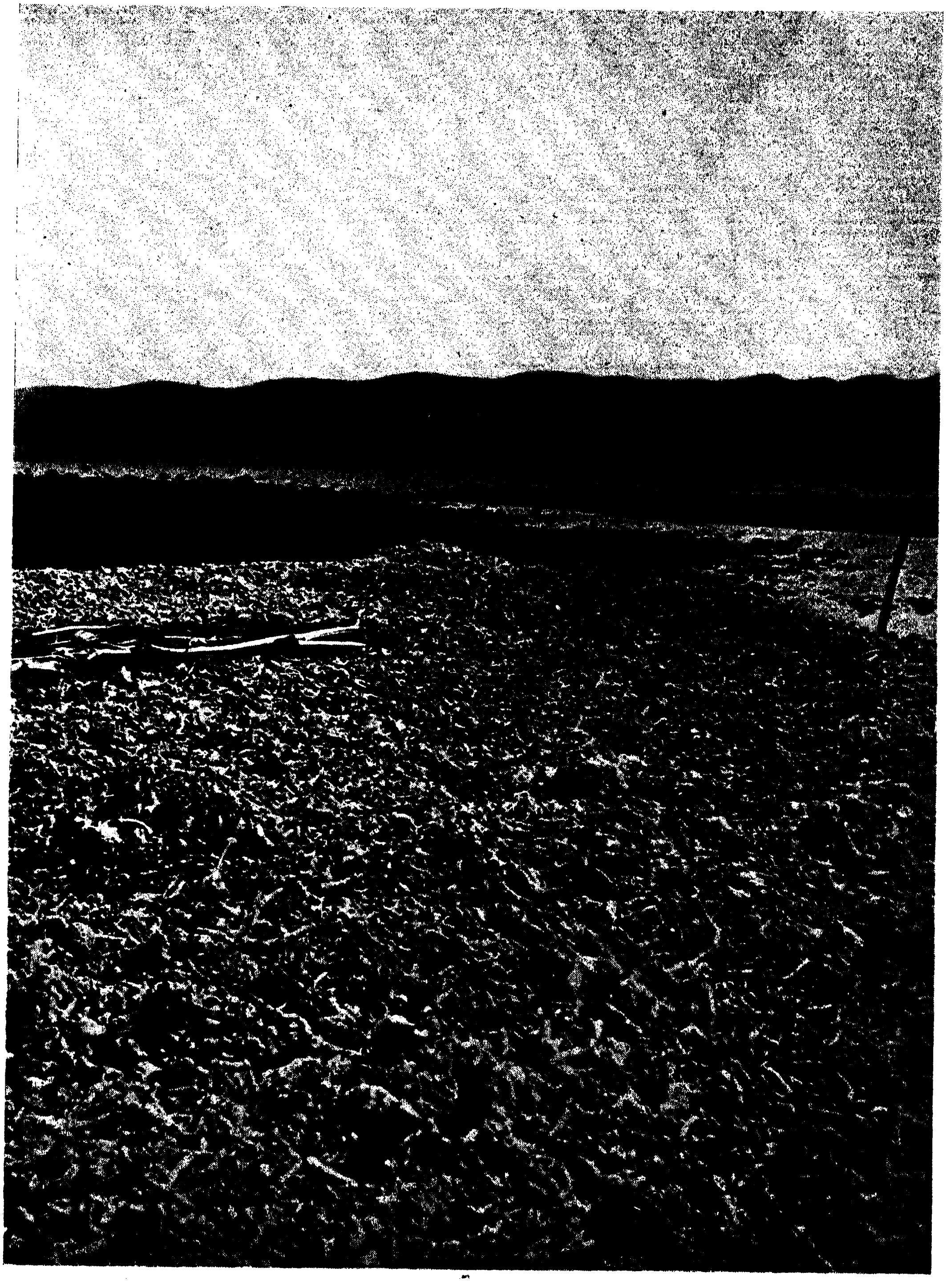
A Red Sea Ctenophoran, *Tjalfiella*, swims about in the early stages only, later becoming flattened and creeping about on the sea-bottom. This, it is suggested, offers a link between the Coelenterata and the Flatworms.

THE FORMATION OF CORAL REEFS

by

DR. J. D. OMMANEY

Corals are exceedingly sensitive to the conditions under which they live. The reef builders cannot live in temperatures lower than 68° F. and they are, for this reason, restricted to a tropical belt between 25° N. and S. latitude. Owing to the temperature distribution of the oceans, there-



A bank of dead coral debris on the Great Barrier Reef of Australia.

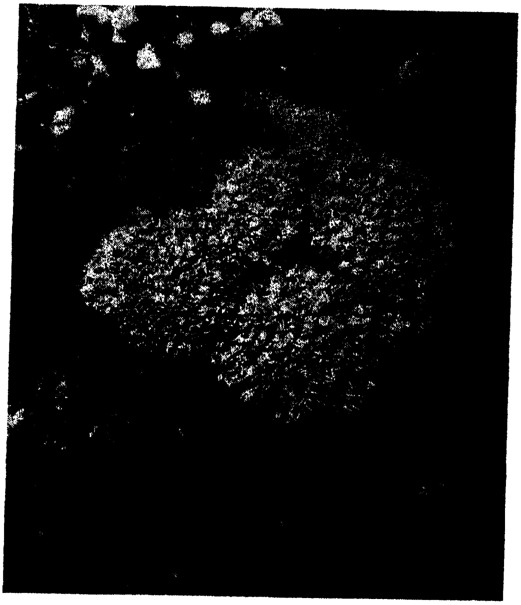
Coral heads on the Great Barrier Reef just submerged, with Mangroves in the distance.

fore, most of the reefs are situated on the western sides of the ocean basins. Since most corals cannot live without their plant guests, bright sunlight is essential for them, so that the vast majority live within the thirty-fathom line. However, they cannot stand long exposure, so they never grow upwards beyond the low-tide level.

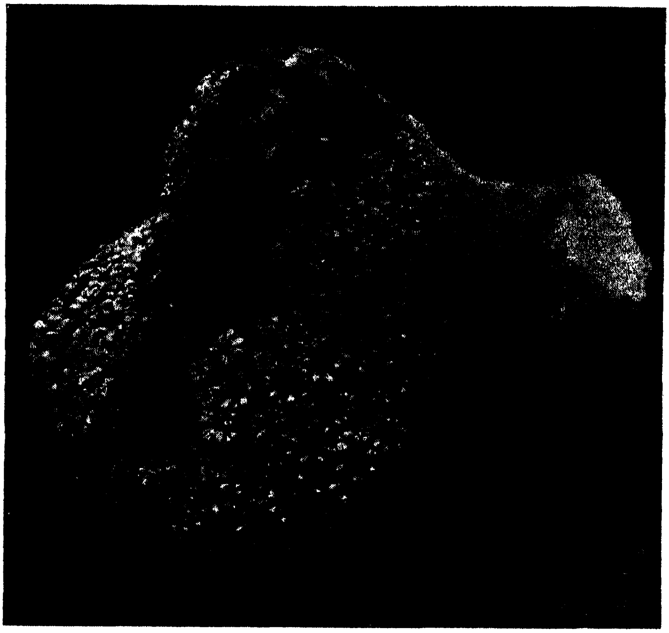
Coral reefs may be of three types: the "fringing" reef living just offshore, separated from the coast by a narrow and shallow lagoon; the "barrier" reef, like the 1000-mile Great Barrier Reef of Australia, lying at a much greater distance from the coast, often several miles wide with innumerable channels through it, with shallow lagoons and occasional wide steamer passages; the "atoll", a ring of growing corals crowned with palm trees and other vegetation, within the middle of the ring a lagoon fifty to seventy fathoms deep, often hundreds of miles from any true land and rising abruptly in the ocean from thousands of fathoms.

The formation of the "fringing" reef is explained by supposing that the corals established themselves originally along the thirty-fathom line and grew upwards and outwards. Upward growth, however, was limited by the low-tide level but outward growth continued on the rubble foundation continually built up at the foot of the reef by the crumbling action of the sea. Thus the line of living corals became carried away from the coast. The greatest coral growth in a reef takes place near the surface and decreases steadily to the thirty-fathom line, ceasing below that. The slope of the outer face of the fringing reef, therefore, would steepen steadily as it grew until it became a precipitous underwater cliff. Meanwhile a shallow trough would be formed between the reef and the coast, partly, perhaps, by disintegration of the rock by animals, partly by the scouring action of waves rushing through or over the reef, and partly by direct solution by sea water. The exact mode of formation of the lagoon, however, is uncertain.

In order to explain the formation of "barrier" reefs and "atolls", Darwin put forward his classical theory based on the facts which he observed during the voyage of the *Beagle*. He



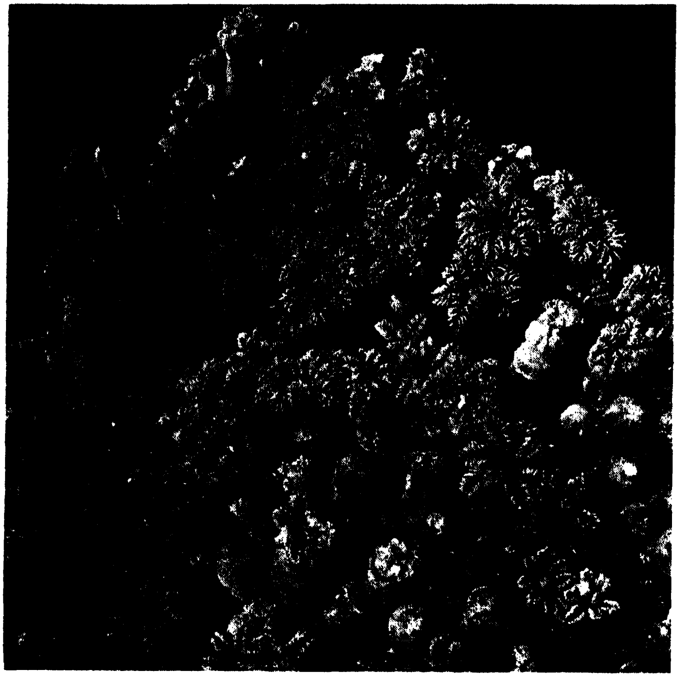
The Alcyonarian, *Xenia*, inhabitant of coral reefs, with a dense mass of tentacles. Its colour, electric blue, is due to the number of blue-green algae in the tissues. This and the three pictures on pp. 159–162 were taken on the Great Barrier Reef.



The brilliant emerald green coral, *Goniopora*, with some of its polyps expanded and some withdrawn.

noticed that corals can only live in shallow water and he therefore concluded that over the whole extent of the coral seas the sea floor and the projecting land has been slowly subsiding for millions of years. Darwin held that "barrier" reefs were formed by slow subsidence of the coast while the coral reefs continued their upward and outward growth, converting fringing into barrier reefs. Atolls were formed by the sinking of isolated mountain peaks until at last only a coral ring remained based on a submerged peak. The American naturalist Dana, who visited the Pacific Islands four years after Darwin, observed that the coasts of such coral islands as Tahiti are all of the "drowned" type with valleys showing no cliffs but gently sloping sides and with rivers opening at their heads. This he took to be an indication of subsidence of the land and as a confirmation of Darwin's theory. At the end of the nineteenth century, however, objections to Darwin's theory were raised, for it seemed that the mere existence of atolls was insufficient evidence, by itself, of any widespread sinking of the land and of the sea floor. Indeed, it seemed that in some areas the coral reefs had actually been raised up, as, for instance, in the Pelew Islands where there are coral reefs which seem to have been lifted some four hundred feet or more. There are places, too, where "fringing" and "barrier" reefs and atolls all exist together. And, though this could be explained by a tilting or unequal sinking of the land, it seemed that some other theory was needed which did not require such widespread subsidence. Sir John Murray put forward the idea that "barrier" reefs must result from the continuous outward growth of "fringing" reefs, spreading outwards on the foundation of their own rubble, while the lagoons were enlarged by the solution of the coral rock. Atolls, Murray held, are based on submarine peaks. And since the peaks could not all originally be of equal height he concluded that those which did not rise to the required height for coral growth were raised to that level by submarine deposits

The Giant Sea-anemone *(Stoicactis)*, of Australia, has its base buried in sand. It is brown or blue in colour and over a foot across.



An Alcyonarian *(Clavularia inflata)* with branched tentacles. All stages can be seen between complete contraction, with the tentacles withdrawn into the body, and the fully-expanded polyps.

laid down on their summits. On the other hand, those which rose too high must have been cut down by the action of the waves. The lagoons, again, had been hollowed out by solution. This theory was widely accepted at the time but there are many objections to it. In the first place, all atolls descend very steeply on their seaward faces to depths of thousands of fathoms and it is not easy to imagine how any deposits could have been laid down on submerged peaks at such a steep angle. Further, it seems unlikely that the slight dissolving action of sea water could have formed the lagoons. It seems more likely that they would be filled up by silt faster than they could be hollowed out by solution.

In 1915 Professor R. A. Daly advanced his "glacial control" theory. He supposed that all modern coral reefs had been formed since the Pleistocene ice age. During that time vast volumes of water were locked away as ice, so that the general level of the ocean sank some thirty or forty fathoms. There was also a universal lowering of the temperature of the ocean everywhere, so that large areas of the tropical seas became too cold for the growth of corals. Many reefs, therefore, died during the Pleistocene age by exposure on account of the lowering of the sea level or through the drop in the temperature of the sea. The new sea level then cut platforms along the coasts and around the islands. After the ice age the sea level rose again, submerging the newly cut platforms to a depth of thirty or forty fathoms. On the seaward edges of these new coral growths began to form by the proliferation of those which had survived. Fringing reefs were thus built up where the platforms were narrow and barriers where they were broad. Atolls were formed on the tops of peaks cut down during the ice age. This theory, it was thought, would account for the flatness of the bottoms of the lagoons and for the fact that all lagoons, both behind reefs and within atolls, were of approximately the same depth. However, it has since been shewn that there is, in fact, quite a wide variation in the depths of lagoons in different places.

The formation of coral reefs, however, still remains something of a mystery and it is probable that there is some truth in all three theories. Some reefs may have been built on sinking coasts, others on banks rising from beneath the sea, while others again may have grown up on platforms cut during the ice age. Darwin's theory, at any rate, is by no means proved, but it is believed that seismographical observations made during the atom bomb test at Bikini tend to confirm it.

CHAPTER IX

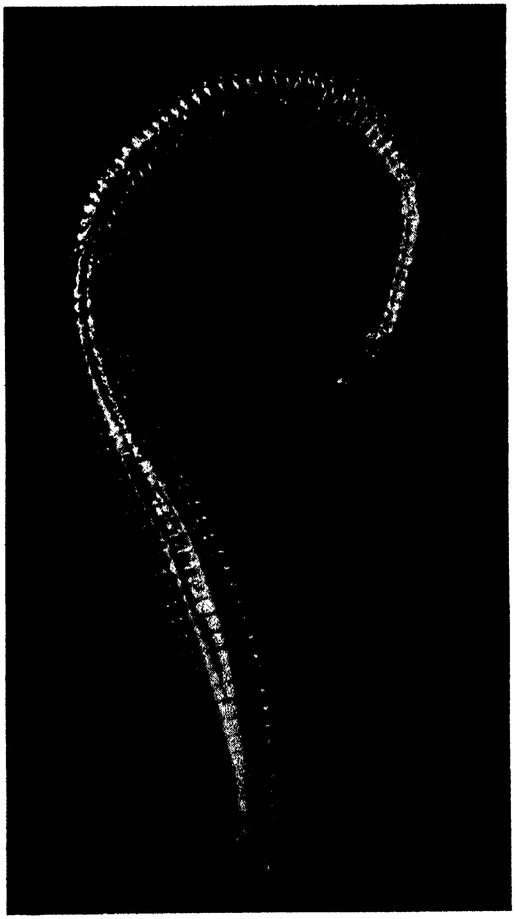
VERMES, OR WORMS

Unter this heading are grouped a number of phyla of worm-like appearance, many having doubtful relationships. It is a grouping of convenience

HERE we include for popular usage a great variety of animals which are zoologically distinct; some indeed which are very far removed from the true worms. In fact, a worm has come to mean almost any small creature long and slender, without obvious limbs and of a crawling habit. Thus at some time or other it included even snakes, certain limbless lizards and a few molluscs, some of the larvae of insects as well as those which are more nearly related to the earthworms. Here we shall consider only those belonging to the 9 phyla as follows:

Phylum Annelida (Ringed worms, marine Bristle worms, Earthworms and Leeches);
Phylum Gephyrea (Bridge worms);
Phylum Rotifera (Wheel-animalcules);
Phylum Gastrotricha;
Phylum Nemertinea (Ribbon-worms);
Phylum Platyhelminthes (Flatworms);
Phylum Nemathelminthes (Roundworms);
Phylum Acanthocephala (Thorny-headed worms);
Phylum Chaetognatha (Bristle-mouthed worms).

All the members of these phyla live in wet or moist situations either in the sea, in fresh waters, in damp earth or in the bodies of other animals; and they include some of the most obnoxiou sparasites, such as the tapeworm, as well as those so beneficial to man, namely the earthworms. All have this in common: that the body, instead of being composed of two layers of cells, is built up from three distinct layers. There is therefore a distinct advance from the Coelenterates and the possession of the third layer has led to a greater specialisation. In the more highly organised worms there is a distinct system of blood vessels, a central nervous system with a very simple form of brain, and a digestive tract with its associated organs. The



Nereis furcata, a marine Bristle Worm. The head is not adorned with a crown of bristles, as in some of its more showy relatives. The segmentation of the body is made more clear by each segment having a pair of parapodia which are at once locomotory, tactile and respiratory. (Twice natural size.)

Sabella, a tube-building marine worm, with its beautiful crown of coloured bristles. (Slightly enlarged.)
(By Courtesy of G. B. Instructional Ltd.)

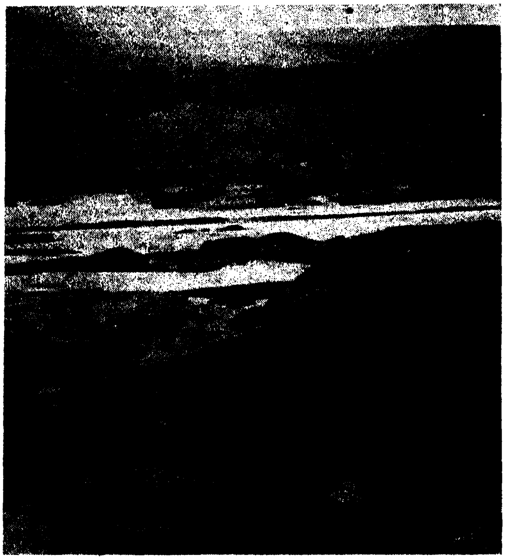
most extensive group is known as the Annelida, which includes the earthworms and marine bristle worms. This is further divided into the Archiannelida, Polychaeta and the Oligochaeta, together with the Myzostomata, a parasitic group, and the Hirudinea, or leeches.

Phylum Annelida
(Earthworms and marine bristle worms)

The most important group from the point of view of the human race is the Oligochaeta or earthworms. These are so familiar that there is little need to describe their appearance, but it may be worth while to recall that the body is made up of a number of rings or segments and that each segment bears several pairs of bristles set in the skin. These can be felt if the earthworm is passed through the thumb and forefinger backwards. It is with these that the worm is able to move about, crawl into its burrow, or anchor itself by its hinder end when a bird seeks to pull it out of the earth. There is an area near the front end where the skin is thickened into a girdle or saddle. This marks the spot where the reproductive organs are lodged and the thickened area is a gland for secreting a cocoon for the eggs. Earthworms are hermaphrodite but not self-fertilising and it is a common sight in the garden in the early morning to see worms pairing, two from neighbouring burrows, with their tail ends firmly anchored in the mouths of the burrows, closely joined at the region of the saddle.

Darwin, in his famous book, *The Formation of Vegetable Mould through the Action of Worms* has given a very complete account of the effects of these animals on the soil; how they swallow large quantities of earth, digest any organic matter contained in it, and evacuate the earth in the form of worm castings. He calculated that earth worms will move some 10 tons per acre in a year, and they are the biggest cultivating agents of all. Not only do they turn the earth over and mix it thoroughly but they aerate the soil by riddling it with their burrows even to a depth of six to eight feet.

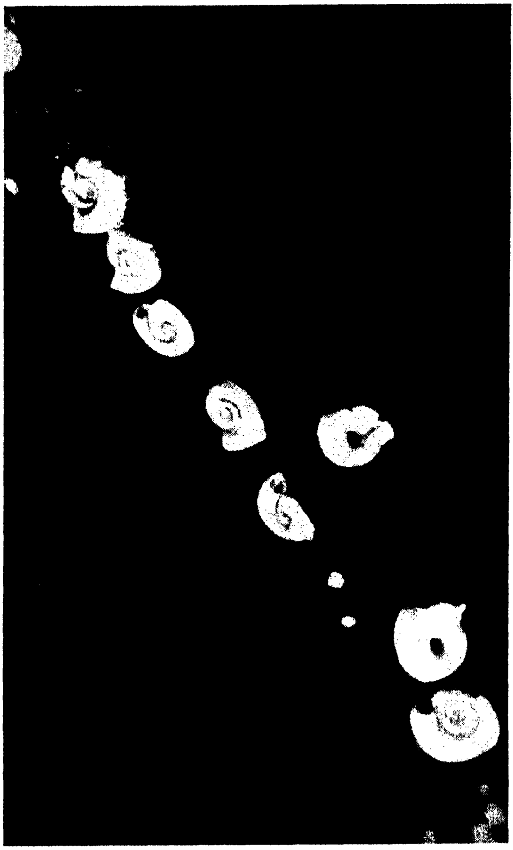
Another interesting thing is that earthworms have no obvious sense-organs: they have no eyes



Many marine worms burrow in the sand, or make tubes in which to live. Some species not only construct tubes of sand, but live in colonies so that they build reefs of considerable proportions, often several feet across.

but will re-act to strong light; they have no nose but at least some sense of smell: they have no tongue but a strong sense of taste; they have no ears but will quickly react to vibration whether through the earth or through the air. A slight consideration of these facts brings us face to face with a very important point, that the sense-organs differ very much in different groups of animals.

The Polychaeta or marine bristle worms differ from the familiar earthworms in several well-marked ways. There is a distinct head region which is usually provided with a number of feelers or tentacles, often with an array of bristles. Often the body can be separated into thorax, abdomen and tail and it is equipped with gills for breathing, cirri or finger-shaped tactile organs, and frequently with elytra or protective scales. Sometimes there are eyes which range from simple pigment spots to elaborate organs with crystalline lenses. Arranged in pairs along the body are parapodia, or feet, often of complex design. The sexes are usually separate but the methods of reproduction vary enormously and are seldom simple. In *Nereis*, the rag-worm, the hinder two-thirds of the body undergoes a complete change at the time of reproduction and the worms swarm on the surface of the sea in enormous numbers during the night and, after discharging their sexual products, usually die. In *Nereis caudata* a very different process takes place. Male and female live in the same tube and there the eggs are fertilised. The male then takes on the maternal duties of incubation and tends the eggs with great care – but the female weakened by her egg-laying, is unable to defend herself and is quickly devoured by the male. *Nereis dumerilii* is polymorphic. That is to say the individuals composing the species can be separated into a number of distinct types. Sometimes the males are small and the females large. Sometimes they undergo a change in the hinder two-thirds of the body and swarm at night. Others lay their eggs in a burrow, are devoured by the male and then the male proceeds to turn into a female. Probably the most famous bristle


Tubes of *Spirorbis*, enlarged three times.

Worms pairing; earthworms are hermaphrodite and in the pairing the individuals fertilise each other. The saddle, or clitellum, seen as a prominent light band in the nearest worm, is used in the process as an organ of adhesion. *(By courtesy of G.B. Instructional Ltd.)*

Worms are not always what they seem. The true worms are usually long and slender, and are distinguished by having the body divided up into a series of rings or segments, with a bunch of bristles on either side of each segment for purposes of locomotion. The sea-mouse (*Aphrodite*) looks from above like a mammalian rodent because the body is plump and the upper surface is covered with a fine 'fur' of bristles. It moves over the sand with a movement and at a speed suggestive of a mouse. If we turn the creature on its back, however, the true character is revealed, for we see the segmented body and the two bunches of locomotory bristles to each segment. (One half natural size.)

worm is the Palolo living off the Island of Samoa. At certain fixed times of the year the hinder part of the body degenerates into a long sac filled with the genital products and when the time comes this breaks away and swarms of them are found on the surface of the sea. At these times they are collected by the natives of Samoa and used as food, and there is a close connection between this swarming and the periods of the moon. A number of worms show this same regularity in sexual activities associated with the phases of the moon.

Another feature of the marine bristle worms is their habit of burrowing in sand, or of constructing tubes of sand, chitin, mucus, or even of lime so that they come to resemble outwardly the shells of molluscs. The bristle worms which burrow in the sand are well known to us from the worm casts which are scattered in profusion over the shore at low tide. Some which build tubes of sand do so in colonies and give rise to considerable sandy reefs on an otherwise flat shore. The Myzostomata, or sucker-mouthed worms, are a small group of flattened, disc-shaped worms living as parasites on other animals, especially on those known as Crinoids, or Feather-stars. Another important group of the Annelida, the leeches figure prominently in the history of the human race, partly from their unpleasant habits of attaching themselves to the body and sucking blood, and partly because this propensity was in former times made use of for medicinal purposes.

Phylum Gephyrea
(Bridge-worms)

The Gephyrea are an example of animals having no obvious relationships with any other group. They are called Bridge-worms because it used to be thought that they bridged the gulf between the Annelida or Ringed-worms and the Echinodermata. Their larvae resemble those of the Annelid worms but the adults are without any appearance of segmentation; and setae, if present, are few in number. There is, however, an oesophageal nerve-ring and a ventral nerve-cord.

Echiurus, six to ten inches long, burrows in sand and mud, has a sac-like body with a spoon-shaped lobe in front of the mouth and a circle of hooks round its hinder end.

Bonellia has a similar sac-shaped body but the lobe in front of the mouth is a long forked whip. The male is minute and worm-like, and lives parasitically in the female.

The rest of this phylum are elongated, sausage-shaped animals, up to a foot long, living in sand and mud, or in holes in rocks. There is here an obvious specialisation in structure arising from the habits, which has resulted in the evolution of a small group of animals of unusual shape and doubtful affinities.

Phylum Rotifera or Trochelminthes
(Wheel-animalcules)

The Rotifers receive much less attention to-day than they did a few years ago, when they were the delight of the microscopist who used his microscope to peer into a new world of life and beauty. They fully deserve that attention for there are few things more fascinating to watch than a *Melicerta* building its protective tube of pellets of mud; there are few things more beautiful than the rhythm of the "wheels". Moreover, Rotifers abound in all fresh waters, although some are marine, and are readily available for study. And, finally, the transparency of the body makes it possible to see every organ of the body at work.

Rotifers are minute, usually microscopic animals with the front part of the body modified into a retractile disc bearing one or two circles of stout cilia which, when in motion, give the impression of rapidly revolving wheels.

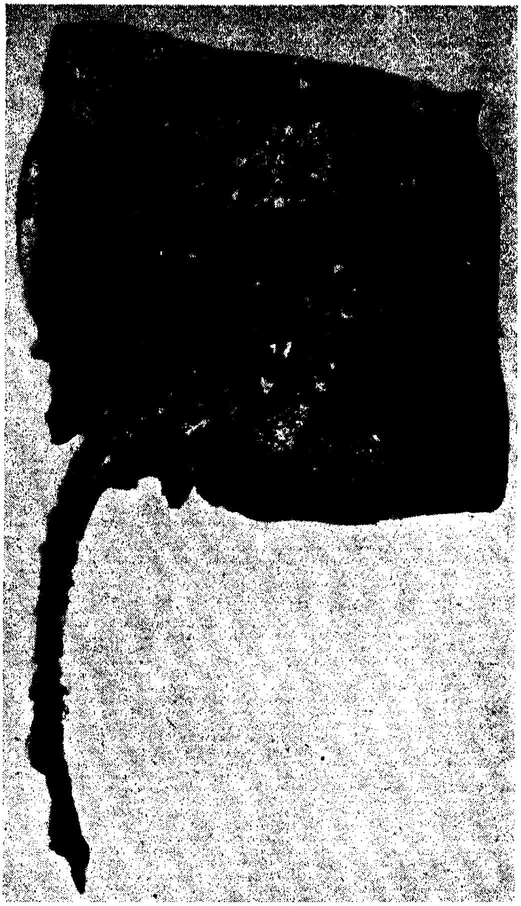
The hinder end is usually extended into a tapering tail, or foot, which can be used for attachment to waterweeds or stones.

The wheels are used in some species as a means of swimming, serving a double purpose in that they sweep food into its mouth at the same time as they propel their owner through the water.

The sexes are separate, but the males are rare and degenerate. Often the females are viviparous; and many are parthenogenetic, two kinds of eggs being laid, thin-shelled summer eggs which develop without fertilisation, and thick-shelled winter eggs giving rise to parthenogenetic females only.

The Rotifer's world, so different from ours, has been aptly described in Hudson and Gosse's famous work: "... if retaining sense and sight, we could shrink into living atoms and plunge under water, of what a world of wonders should we then form part! We should find this fairy kingdom peopled with the strangest creatures – creatures that swim with their hair, that have ruby eyes blazing deep on their necks, with telescopic limbs that now are withdrawn wholly within their bodies and are now stretched out to

Two examples of the Sea-leech, *Pontobdella muricata*, showing the suckers at each end of the body. (Twice natural size.)



A Thornback Skate *(Raia clavata)* with three leeches attached to it.

many times their own length. Here are some riding at anchor, moored by delicate threads spun from their own toes; and there are others flashing by in glass armour bristling with sharp spikes or ornamented with bosses and flowing curves; while fastened to a green stem is an animal convolvulus that by some invisible power draws a never-ceasing stream of victims into its gaping cup, and tears them to death with hooked jaws deep down within its body. Close by it, on the same stem, is something that looks like a filmy heartsease. A curious wheelwork runs round its four outspread petals; and a chain of minute things, living and dead, is winding in and out of their curves into a gulf at the back of the flower. What happens to them there we cannot see; for round the stem is raised a tube of golden brown balls, all regularly piled on each other. Some creature dashes by, and like a flash the flower vanishes within its tube."

The Rotifers have a brain, represented by a nerve-ganglion, and usually one or two simple eyes. They have usually three feelers, also armed with delicate sensory hairs. Yet it is surprising how quickly they will respond to a slight vibration; the slightest jolt to the microscope and "like a flash the flower vanishes within its tube".

Phylum Gastrotricha

The members of this phylum represent one of those puzzling enigmas met with every now and then in the Animal Kingdom, which defy interpretation and almost defy classification. In this instance, we have a small group of minute freshwater animals, no more than a hundredth of an inch long, multicellular, with a mouth and digestive tube, with the body covered with cilia and bristles, yet resembling superficially the infusorian Protozoa.

Phylum Nemertinea
(Ribbon-worms)

These are a class of worms with elongated, unsegmented bodies, slender and more or less flattened, without setae or other appendages but covered with cilia. They range in length from a fraction of an inch to several yards, and are often vividly coloured. Mostly marine, they burrow in mud and sand, feeding on tube-dwelling worms. Their characteristic feature is a long proboscis which lies in a sheath running above the digestive tube. The proboscis is attached to the hind end of the sheath by a band of muscle and lies in a fluid filling the sheath. By contraction of the walls of the sheath, pressing on the fluid, the proboscis, sometimes armed with stinging-cells like those of jelly-fish and sea-anemones, is shot out; and it is with this that the tubiculous worms on which it feeds are extracted.

Phylum Platyhelminthes
(Flatworms)

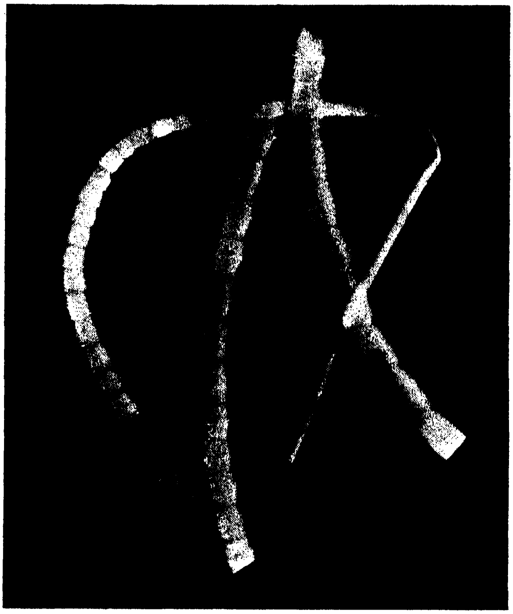
The Flatworms are divided into the Turbellaria or Planarians, the Trematodes or Flukes, and the Cestodes or Tape-worms.

Turbellaria

The Turbellaria or Planarians are soft, flat and unobtrusive, mostly very small, though some may reach half an inch long, while *Bipalium kewense* may attain a foot in length. They may be marine or freshwater, and a few live on land. The latter are often brightly coloured and live under logs or in decaying vegetation, feeding on earthworms, snails and insect-larvae. The aquatic forms creep over rocks and the surface of the mud, or swim by flapping movements of the body, feeding on other animals.

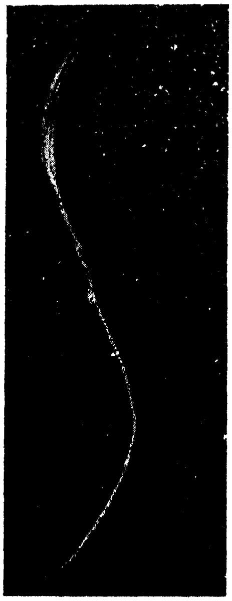
The name Turbellarian is derived from the Latin *turbellae*, because of the bustle or stir caused by the cilia coating the surface of the body, and by means of which they glide about.

An interesting exception to the otherwise carnivorous group is found in *Convoluta roscoffensis*, the tissues of which contain a symbiotic green alga by which agency *Convoluta* builds up carbohydrates in the same manner as a plant. In many respect the Turbellaria form a link between the Coelenterata and the other invertebrates. The gut has only a single opening to the exterior by which food is taken in and waste matter passed out. At the same time there are primitive excretory organs, comparable to the nephridia of the Annelid worms. Moreover, they have the strong regenerative powers of the Coelenterates. A Turbellarian can be cut into small pieces and each piece will grow into a new animal. Conversely, they are capable of undergoing prolonged fasts, feeding on their own substance. A well-known case is that of a Turbellarian half an inch long which lived for nine months without food and measured only a seventh of an inch at the end of that time.



Tapeworm from a dog. The narrow end includes the head, from behind which the segments are being continuously budded off. (Natural size.)

The Trematoda or Flukes

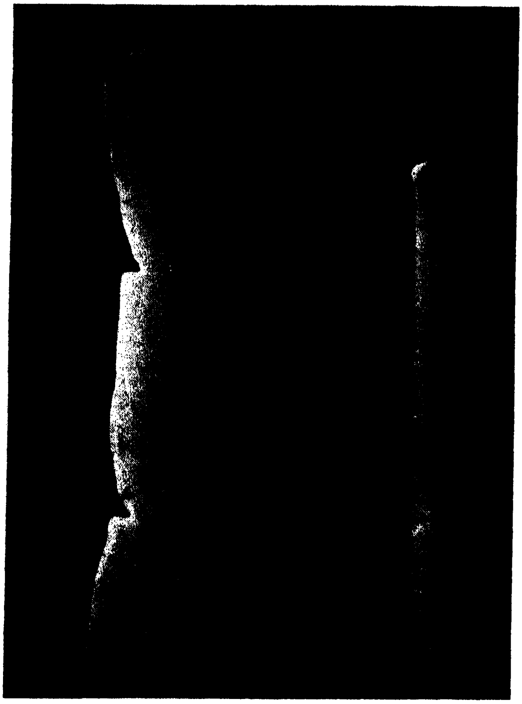


Bipalium kewense, one of the Land Planarians or Flatworms. It lives under logs and vegetation, and may reach a foot in length.

The Trematodes are divisible into two groups, the Monogenetica and the Digenetica, the first being mainly external parasites and the latter internal parasites. Another difference is that in the monogenetic forms the young do not need an intermediate host for their development, and often resemble their parents from the moment they are hatched. The digenetic forms pass through a complicated life-history involving the occupation by the larva of a host, other than that inhabited by the adult, and several marked changes in vorm. The monogenetic flukes are leaf-shaped and flattened, with a group of suckers at the hind end and one either side of the mouth at the front end. There is a well-developed digestive system and the body is covered with a well-marked cuticle but is without the cilia so characteristic of the Turbellaria. They are found, for the most part, on the outside of the body in tropical freshwater crayfish and crabs, where they feed on any small organisms that may come their way; others occur on marine and freshwater fishes and on amphibia. A typical example is *Polystomum*, except that it is foundin the bladder of a frog, hanging on by its suckers, and lives by sucking the blood of its host; and although having the characteristic form of the monogenetic Trematode it is more like the digenetic forms in its habits.

The best-known digenetic Trematode is the liver fluke of the genus *Fasciola*. The common liver fluke, *F. hepatica*, infests the livers of cattle, pigs, even of man occasionally, but is especially common in sheep. It has a complicated life history. The adult lives in the bile duct and its activities are almost entirely restricted to feeding and laying eggs, for it is hermaphrodite, and a single fluke may lay half a million eggs. Since a single sheep may contain up to 200 flukes the parasitised animal may be the receptacle for anything up to 100,000,000 eggs. But this is not the end of the story.

Each egg, if it happens to reach water, after being carried out in the excrement of the sheep, develops into a free-swimming larva, the miracidium, which attacks and enters the tissues of a water snail, of the genus *Limnaea*, where it



On the right the head of a tape-worm, armed at the top with a circlet of hooks and with a ring of four suckers just behind it. On the left three mature segments. Each segment consists of little more than a mass of reproductive organs, and when mature is almost literally no more than a sack filled with eggs. The genital pore can be seen on the right-hand margin of each segment.

develops into a bladder-like stage, the sporocyst. The contents of the sporocyst divide into a number of worm-like rediae, and each redia may give rise by budding to further rediae, or to yet another form known as a cercaria, a tadpole-like creature best described as resembling the adult with the addition of a tail. They pass out of the snail, lose the tail and surround themselves with a protective cyst, and a sheep drinking water or eating wet grass infested with cysts causes the cycle to start all over again.

Inside the sheep, or other suitable host, the digestive juices dissolve the cell-wall, the young fluke bores its way through the tissues of its host until it reaches the liver, and eventually the bile ducts, where it develops into the adult.

The disease so caused is known as the rot, and a large number of sheep are killed by it each year. The high rate of reproduction shown by the fluke means, however, that only a very small percentage reach maturity, the great majority perishing before being taken up by a host.

The well-known disease of Egypt and other parts of Africa, Bilharziasis, is caused by a fluke, *Schistosoma (Bilharzia) haematobia*, which infests the blood-vessels and urinary organs of human beings.

The Cestoda, or Tape-worms

The next group of flatworms is equally unpleasant. The Cestodes or Tape-worms are with rare exceptions parasitic in the alimentary canals of vertebrates. Some are not unlike the Trematodes but the majority consist of a head followed by a chain of segments, the whole often attaining a length of twenty feet or more.

A good example of the Cestode is the Pork Tapeworm, *Taenia solium*. The adult lives in man, the intermediate host being a pig. The eggs are taken up by the pig with its food, and the larva hatches in its gut, whence it burrows its way into the blood vessels and comes to rest in the muscles. There it hangs on by its three pairs of hooks and turns into a bladder-shaped creature and proceeds to develop four muscular suckers and a crown of hooks. This is known as the cysticercus. If pork, containing it, is eaten raw or only partially cooked, the cysticercus turns itself inside out, attaches itself to the wall of the gut and proceeds to bud off segments from behind the head, as the cysticercus now becomes. Each segment is filled with eggs, several millions in each, and these are eventually passed out with the faeces and, if picked up by a pig, the cycle begins again.

The mature tapeworm may consist of 2000 or more segments in addition to the head, looking like a length of dirty-white tape. There are no organs of locomotion, no senses organs or digestive organs, not even a mouth. The tapeworm lies bathed in the nutrient fluid of its host, absorbing food through its whole surface – and reproducing itself!

Phylum Nemathelminthes
(Roundworms or Nematodes)

The Nematodes, which include vinegar-eels, hookworms and horse-hair worms, are very numerous. The majority are free-living, but a number of them are partially or wholly parasitic and are found everywhere on land, in the sea and in fresh water. Some of the free-living forms attack other small animals; some are the cause of disease in crops and other plants; and others feed on decaying matter. Perhaps the best way of dealing with this most numerous and unpleasant group will be to examine the life-histories of the better-known of them.

Probably the most familiar is the roundworm to which human beings are prone, especially children. White or reddish-brown in colour, it may be five inches long, and a quarter of an inch in diameter. It may infest the intestine in large numbers, obstructing the gut and causing a poisoning of the nervous system. Infection is caused by swallowing the eggs – of course, inadvertently – which hatch in the small intestine. The young worms bore through the wall of the intestine into the blood-vessels and are carried to the lungs, whence they make their way up the windpipe into the throat and are swallowed, thus reaching the intestine to grow into adults.

The hookworm is about a twenty-fifth of an inch long, white and thread-like. It gains entrance to the human body by boring through the skin of the bare foot. It makes its way through the blood-vessels to the lungs, thence to the windpipe and throat to be swallowed. Arrived in the intestine it attaches itself to the wall and sucks blood. In cases of heavy infestation the patient becomes dull and lazy, anaemic and very unfit mentally and physically.

A group of Arrow-worms taken in a townet. A young gurnard is seen with them. (Five times natural size.)

Ascaris, roundworms, from the intestine of a horse. Their size can be judged by comparison with the shell of the snail, *Helix aspersa*.

Perhaps the worst Nematode from the point of view of human beings is the one responsible for the disease known as trichinosis. It lives in the muscles of pigs, and pork eaten raw or only partially cooked may result in its transference to a human body where, it forms a cyst. Such cysts are particularly found in the diaphragm, tongue and eyes, and whereas there are remedies to use against the roundworm and hookworm there is none for the trichinosis worm.

The cooking of animal flesh, wearing of shoes and good sanitation have reduced enormously the danger from nematodes in civilized communities.

Phylum Acanthocephala
(Thorny-headed worms)

This is a group of animals so modified in adaptation to a parasitic life that their relationships are even more obscure than those already considered. They have a proboscis armed with recurved hooks, and are without digestive organs, nourishment being absorbed through the the skin. The adults live in the alimentary canal of vertebrate the larvae in invertebrates.

Phylum Chaetognatha
(Bristle-jaws or Arrow-worms)

The "Arrow-worms" form part of that vast host of small creatures of many kinds known as the Plankton. They prey upon jelly-fish, small crustacea and larval fishes, but in turn furnish the food of a number of adult fishes.

Their bodies are transparent, about an inch long, and torpedo-shaped with one or two pairs of small fins, and a horizontal tail-fin. The head is hood-shaped and bears a number of sickle-shaped hooks the points of which, when at rest, converge towards the mouth. In feeding the hooks are automatically spread wide when the mouth is opened for the capture of prey.

HELMINTHS AND HUMAN WELFARE

by

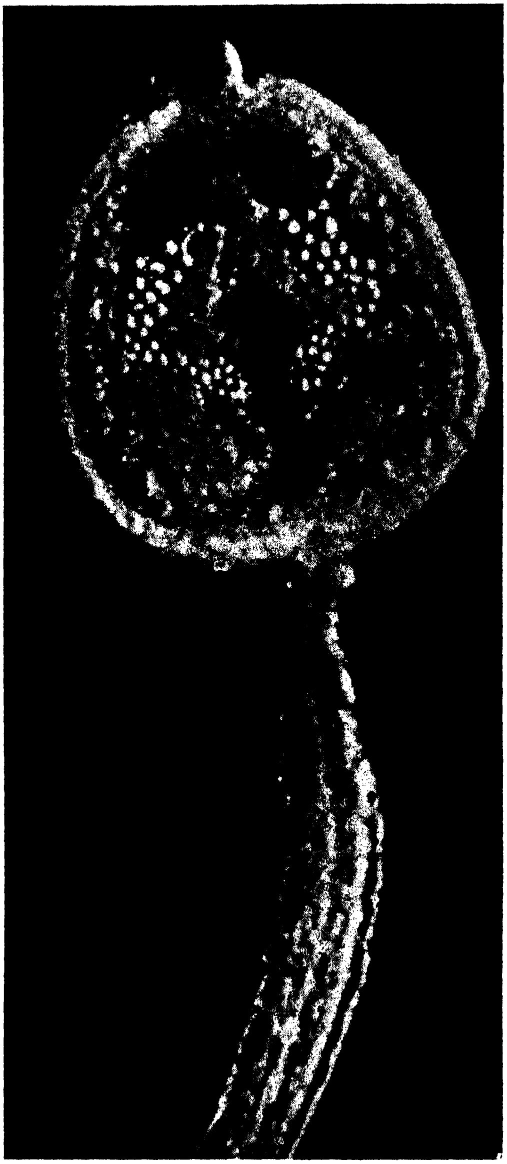
DR. BEN DAWES

The flatworms and roundworms, known collectively as helminths, are not exclusively parasitic, but the vast majority live on or in various animals that provide both food and shelter and are called the hosts. These parasites are presumed to have arisen from free-living forms which became the messmates of other animals. Loose associations were at first formed, perhaps merely the sharing of food and shelter, as illustrated by the commensal forms amongst the Turbellarians. After learning the first trick of gaining attachment to some animal and holding on, the more venturesome of them acquired the habit of entering the body of their host, and learned to feed on its tissues. Many degrees of penetration are illustrated in trematodes alone, for some of these parasites stay in the mouth, or else in the cloaca, while others penetrate into the stomach and intestines, even into less accessible organs such as the lungs, liver, kidneys, heart and blood vessels. Parasites of the gut may utilise the predigested food of their hosts and parasites of the deeper tissues find nutriment in the body liquids. But it was no great step from these food-stealing habits to the more drastic procedure of eating the lining of the host's intestines and bile ducts.

The effects of parasitism bear on both the host and the parasite itself, though we are more concerned here with the effects on the host, which may be robbed of the food it has won, so that it suffers inanition, poisoned by the excretions of the parasites or otherwise injured. A single tape-worm several yards long may seriously impoverish human nutrition, roundworms in the intestines may cause sickness and a severe urticarial rash, while hookworms erode the tissues and cause severe anaemia through loss of blood from ruptured vessels. When the host's tissues are damaged there is also the great likelihood of disease brought about by invading micro-organisms. Further, immature parasites may lodge in unusual situations, such as the eye and the brain, with dire consequences. Microscopic parasites may injure the host by blocking blood vessels or lymph channels. Certain minute worms crowd minute lymph vessels, but do not prevent the passage through of liquid lymph, though the return circulation from a limb or some other part of the body is not endowed with sufficient fluid pressure to permit the lymph to leave, with the result that it remains and coagulates in steadily increasing amount until the part has swollen to the enormous size characteristic of elephantiasis. One other type of damage is that caused by the spined eggs of some blood flukes (schistosomes) which work their way through the wall of the rectum or the urinary bladder, causing blood to appear in the faeces (dysentery) or in the urine (haematuria). Heavy infections of microscopic parasites may be very harmful to the host, whereas light infections do little harm and by allowing the host to develop an immunity reaction may protect it from heavier infections subsequently.

The larvae of many parasites must emerge from the host inhabited by their parents and spend a brief period of freedom in quest of a new host. This is the most vulnerable period of the life history and if the larvae can be killed, or even only avoided, diseases caused by their later development can be eradicated. The miner's hookworm, *Ancylostoma duodenale*, lays her eggs in the human intestines and they are segmenting by the time they pass out with the faeces. After a day or two in the open when conditions are favourable the embryos hatch out, grow rapidly and moult twice, retaining the cuticle as a loose protective sheath. In about five days the larvae are ready to infect another miner and generally they enter his body by the most direct route, through the skin. In ten days more they may have established themselves in his intestine after making an extensive migration through his tissues. They enter some vein, pass in the blood stream to the heart, thence to the lungs, where they emerge from the blood and enter the air sacs, later migrating along the bronchial tubes to the trachea. Here they irritate the host and are coughed up into the mouth. If they are swallowed they are unharmed by acid and enzymes in the stomach and quickly establish themselves in the intestines.

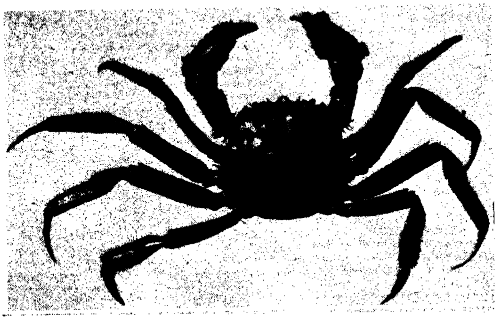
Some parasites require two, or three, and even four different hosts for completion of the life cycle. The pork tape-worm, *Taenia solium*, requires a pig as well as a human being. Its eggs develop into six-hooked embryos (hexacanths) while still enclosed in their shells inside decaying fragments of tape cast out with human excrements. If a grovelling pig takes the eggs up with its food the embryos emerge in the pig's intestines, pass through the lining, get into the blood stream and are carried by it to various organs—the heart, the tongue, the forearm, the neck and the thigh, as a rule. Here the larvae develop into bladder worms (*Cysticercus cellulosae*) within ten weeks, but the parasites remain viable for many months thereafter, though they do not develop further unless eaten in this condition with imperfectly cooked pork.



The Cercaria of a liver-fluke. (Magnified 200 times.)
(By Courtesy of G. B. Instructional Ltd.)

If this happens, the bladder-worms, which already have the fully-formed head (scolex) of a tape-worm, soon settle down in the human intestines and set to work producing the characteristic chain (strobila) of segments by a process of budding.

The digenetic trematodes, or flukes, develop a succession of larvae—miracidiae, sporocysts, rediae and cercariae—all of which generally inhabit the tissues of snails, where they multiply by a form of asexual reproduction. Enormous swarms of the tailed larvae (cercariae) emerge from the tissues of snails and come into the open in quest of further hosts. Like the liver fluke of the sheep, *Fasciola hepatica*, the human intestinal fluke, *Fasciolopsis buski*, encysts on vegetation, depending on a passive mode of entry into the final host. A single tuber of the water caltrop (*Trapa natans*) may bear several hundreds of encysted larvae, and as these are bought by natives in Chinese markets and eaten on the spot heavy infection occurs. In the Philippines, the fluke *Euparyphium ilocanum* is acquired by the natives because of the custom of eating the mollusc *Pila luzonica* straight from the shell. In this instance the cercariae penetrate the mollusc in order to encyst, and they are unharmed by the condiments used to make the mollusc more palatable. The notorious human lung fluke *Paragonimus westermanii* of South America, India and the Far East, lives in human bronchioles and lays eggs that are cast out in sputum. In this instance the cercariae encyst in various freshwater crustaceans, and infection follows when imperfect cooking leaves the larvae unharmed. The human liver fluke of the Orient, *Clonorchis sinensis*, employs many species of freshwater fishes as intermediate hosts, and some at least of these are used as food. The larvae lie just underneath the skin of the fish and are readily killed by heat, but bad cooking enables them to survive and inflict suffering on unsuspecting natives.



The Mitten Crab, so called because of the covering of hairs (the mittens) on the claws of the male, is responsible in China for the disease known as paragonimiasis, caused by a lung fluke *(Paragonimus westermanni)* carried by the crab.

The human blood flukes (schistosomes) share with hookworms the power to penetrate human skin, so that traditional carelessness about food and slipshod culinary methods do not account for their dissemination. The eggs contained in human faeces used for fertilising rice and other crops hatch out and provide a reservoir of larvae that, after a phase of development in suitable snails, can attack the native farmer or housewife through bare hands and feet. Other insanitary habits also create reservoirs of disease which cannot be combated entirely by means of drugs, but call for other and better means of attack.

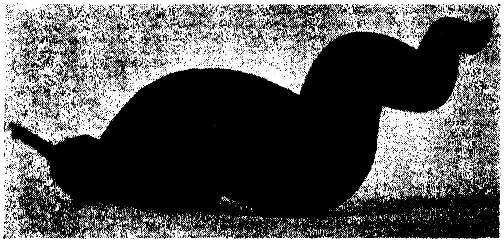
The best method of control of parasitic worms is to apply the knowledge of their modes of propagation. Practical difficulties often stand in the way of perfect control, but we have to find the weak links in the chain-like life cycles and break them in order to secure a measure of success. This may be quite easy once we have become armed with knowledge. We need only avoid establishing contact with the embryos of hookworms or the cercariae of schistosomes during drinking, washing, working or bathing operations to frustrate them completely. Other methods of control may include more drastic measures – the draining of marshes favourable to snails that harbour cercariae. The scrutiny of food to ensure that it does not contain apparently insignificant parasites, insistence on proper cooking to kill any that may escape detection and other simple measures may be most effective. Prevention is better than cure, and more knowledge about parasites and parasitism will eventually enable us to get rid of much suffering caused by diseases that are all too prevalent in the world to-day.

CHAPTER X

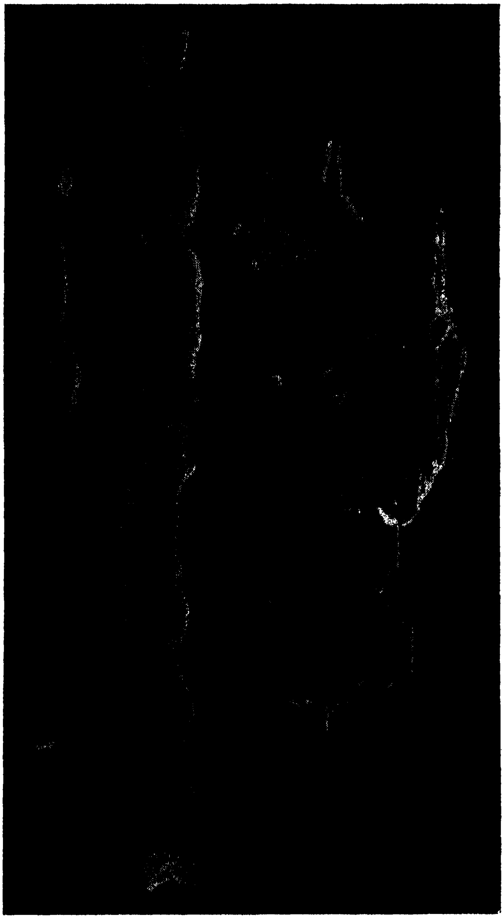
ABERRANT ANIMALS

STARFISH, SEA-URCHINS, SEA-LILIES AND SEA-CUCUMBERS

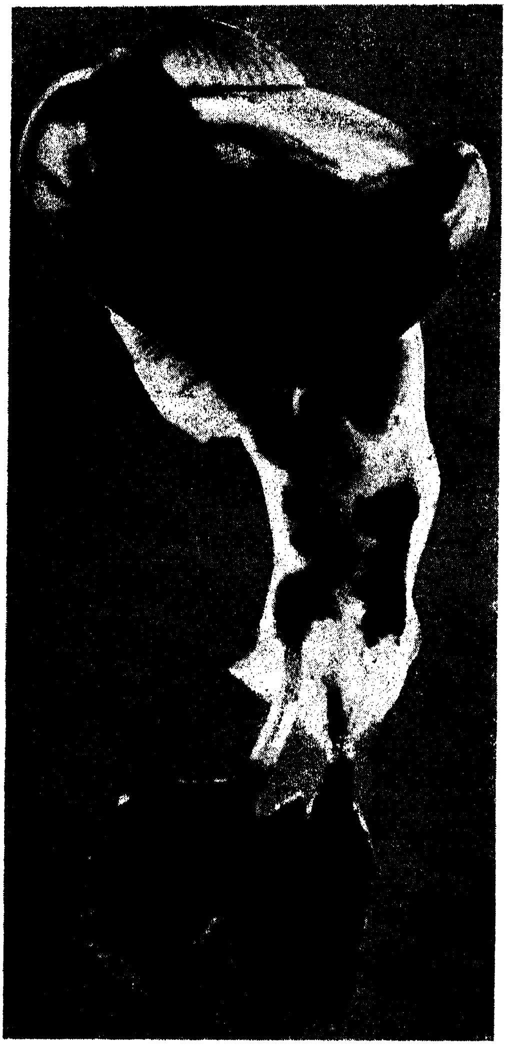
AS we pass from one group of animals to another, from the unicellular Amoeba to Man, we find a comparatively orderly sequence which is, reasonably enough, accepted as the course of evolution within the Animal Kingdom. Each succeeding group of animals is more highly-organised than the one before; and the tendencies manifest in one group become more strongly pronounced in the next. It is not difficult, for example, to trace the steps by which the simple digestive cavity of a *Hydra* becomes elongated and differentiated into a gullet, stomach and intestine. In every group, however, one or more species are found to have departed from the general plan. They have by the greater use, and consequent development, of one particular organ, or group of organs, brought about a disproportionate growth in one or more parts of the body. In a few cases, the process has gone so far that the animal concerned appears to belong to an entirely different group. The Shipworm is a good illustration. Here is an animal with a long cylindrical body that spends most of its life burrowing in the timbers constantly immersed in sea-water. Originally it was thought to be a worm, and, indeed, it has a very strong resemblance to the burrowing creatures we know as worms, but its larval life is similar to that of molluscs, its anatomy is molluscan, and at its front end it bears a pair of small but typical



The Scalariform Snail is an aberrant type.



Two Shipworms *(Teredo navalis)* damaged in being extracted from the burrows. At the front end (below) can be seen the shells, at the hind end the pair of siphons typical of mollusca. To the right is a piece of timber bored by the shipworm.



Larva of a Shipworm. The shells which mark its molluscan affinity are greatly pronounced as compared with the adult. (Magnified 300 times.)

mollusc shells. In other words, the Shipworm is a mollusc.

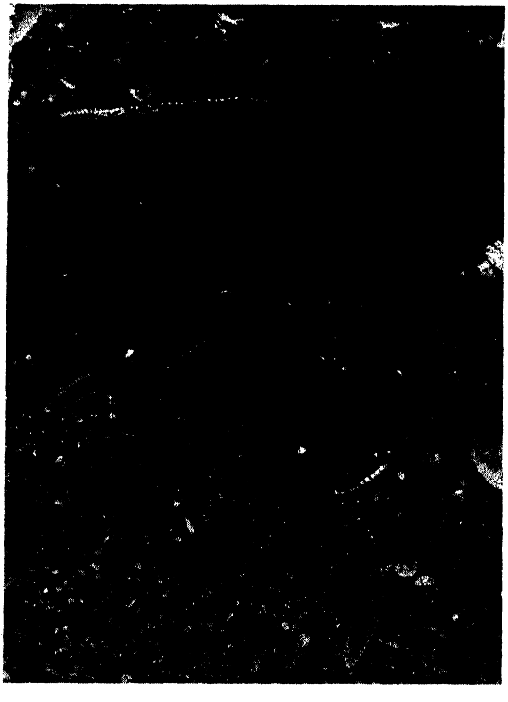
Animals that depart radically in character from the order, family or genus to which they belong are said to be aberrant; and the phylum Echinodermata, or spiny-skinned animals, is the most strikingly aberrant in relation to the Animal Kingdom as a whole. The shape of the body, method of locomotion, anatomy and behaviour are such as to make their relationship with other animals very obscure. They stand alone, an apparently meaningless offshoot of the family tree.

Phylum Echinodermata
(Starfish and their relatives)

General characters. The Echinodermata are radially symmetrical, marine or, rarely, living in brackish water; the skeleton consists of calcareous rods and plates embedded in the skin, often joined at their edges to form a shell, usually covered with tubercles or spines, or, in the Holothurians, taking the form of scattered spicules; they have a spacious body cavity and a system of canals serving for respiration or locomotion, or both; the larvae are totally unlike the adult, and are bilaterally symmetrical.

Classification

The phylum consists of five classes:
Class Asteroidea (Starfishes)
Class Ophiuroidea (Brittle-stars)



The Starfish *(Asterias rubens)* common off the coast of Europe. The smaller specimen has lost three arms, one of which is beginning to grow again.

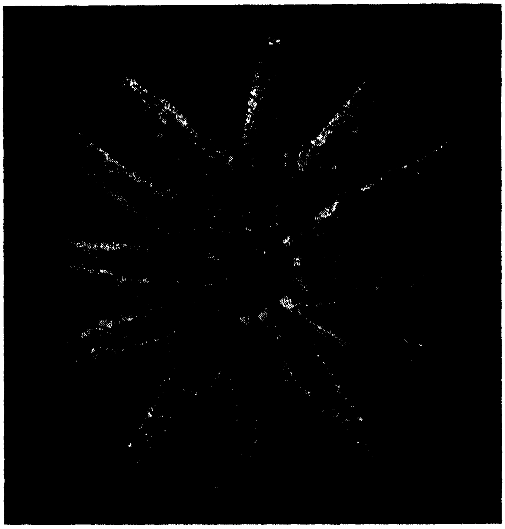
Class Echinoidea (Sea-urchins)
Class Holothuroidea (Sea-cucumbers)
Class Crinoidea (Sea-lilies).

In spite of the marked differences between them the Echinoderms have so much in common that we can best begin with a detailed description of a starfish and then examine how the others differ from it.

Class Asteroidea (Starfishes)

A starfish consists of five arms radiating from a common centre, and was originally classed with sea-anemones and jelly-fish, as one of the Radiated Animals. This was in contrast to the more familiar bilaterally-symmetrical animals, that is those with an obvious head and tail, and with a body divisible into two more or less symmetrical halves by a line running from head to tail.

A portion of the undersurface of *Solaster papposa*, showing the mouth and the two rows of retracted tube-feet along the groove running up each arm.



The 12-armed Starfish, *Solaster papposa*, seen from below.

If we turn a starfish over and examine the undersurface, we see a groove running down the centre of each arm, and where these meet is a small opening, the mouth. On either side of each groove, running from one end to the other of each arm are rows of very small, finger-like processes constantly but slowly moving. Some are being drawn in to the surface of the arm until they almost disappear, others are being extended, and as they extend the free end becomes dilated into a flattened disc, and is waved about in a slow, searching movement. These organs are unlike anything found in any other group of animals. They are the tube-feet of the starfish, the organs of locomotion. Place your finger against them and each flattened disc becomes a sucker taking hold of your skin. Leave the starfish on its back and watch how it gets back into the normal position. The tip of one arm turns over and the tube-feet take hold of the coherent surface of the sand. With this leverage, the arm slowly turns more and more, enabling more tube-feet to get a grip. With the other arms co-operating in a similar manner, the whole body continues the movement until in a slow somersault the starfish has regained its correct position. This done the tube-feet at the end of one of the arms release their hold and stretch out to their full extent to take hold of the surface once again. Then they begin to contract and the pull so exerted draws the starfish an almost imperceptible distance over the sand. Slowly the movement quickens for, although we cannot see them, the tube-feet all along the undersides of the arms are co-operating in this and the starfish, gathering speed, moves away.

The back of a starfish is covered with warts, each a calcareous plate of irregular outline embedded in the skin. Some of the larger bear short spines, and whereas some appear to be scattered without order over the surface, some are arranged in a definite pattern, forming a ring round the outer edge of the central part of the body, connected to a line of them running down the centre of each arm to the tip. At one point on the central ring, there is one plate larger than the rest. This is the madreporite, with a minute opening in its centre, hardly visible to the naked eye, which communicates with a tube running down through the body where it connects with a system of tubes running through the arms. These tubes are connected with the rows of tube-feet, and the whole forms a simple but effective hydraulic apparatus. Water drawn in through the opening in the centre of the madreporite is pumped into the tube-feet, when it is necessary to extend them, and is withdrawn when it is necessary to retract them.

This series of delicate tubes is capable of exerting a pressure of 350 lb. per square inch, obviously unnecessary merely to enable so light an animal to move about, but, like all animals living in shallow sea, a starfish needs to find a way of combating the tremendous action of the waves, especially during gales, when the inshore seas are lashed to a fury. During such times crabs and others shelter under rocks, or in their crevices, or bury themselves in the sand, while the starfish clings to the rocks, flattening itself against the surface, holding on with all the power of its numerous tube-feet.

The tube-feet are, however, used for another purpose. Starfish are carnivorous, feeding mainly on shellfish, and anyone who has tried to prise open the shell of an oyster will know how the animal will resist. Having selected an oyster, a starfish wraps itself around the shell and fastens its tube-feet securely thereon. Then it begins to pull. The oyster resists, and the power in its muscles is approximately equal to that exerted by the starfish, but the staying power of the latter is greater and after a time the oyster gives way and its shell comes open. Holding the shell apart, the starfish extrudes its stomach and engulfs the soft body of the oyster, sending out a stream of gastric juices that slowly digest the oyster. Having neither teeth nor jaws, the starfish must wait until the oyster's body is reduced to soft, semi-fluid mass before it dare relax its hold.

A starfish has no obvious sense-organs but at the tip of each arm is one tube-foot incapable of being retracted. This is used as an organ of touch. Just above it there is a small red spot, a simple eye. But in its search for food, it is probable that the animal relies less on touch or sight than on a combined sense of taste and smell. If, for example, meat juices are poured into a tank containing starfish, they become very active.

On the surface of the starfish's body are two sets of structures best seen with a hand-lens. Between the plates studding the surface are many small tufts of skin which are really irregular bladders. Through them oxygen is taken from the sea to aerate the fluid filling the internal cavities of the body. Also scattered among the plates are patches of minute pincers, the pedicellariae, each composed of two or three jaws, set on slender stalks and moving at their lower ends on ball and socket joints. Their function is to keep the surface clean so that the animal can breathe.

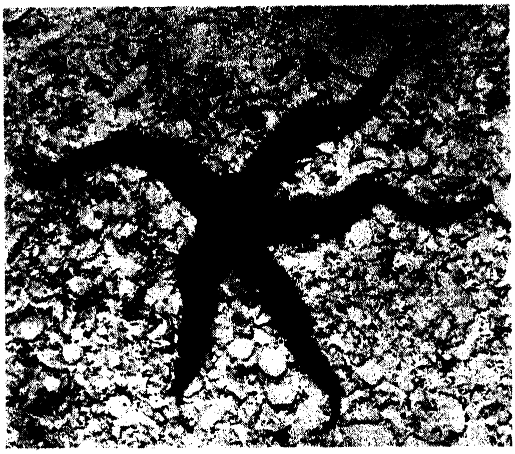
At certain seasons, the sea swarms with eggs or larvae of all kinds. Only a percentage of these survive, but the larvae of sponges, hydroids, barnacles and other sessile organisms settle down on the bottom after their brief free-swimming existence, metamorphose and fix themselves to any solid object on which they may come to rest. In this way stones, rocks, seaweeds, and the shells of mussels, oysters and other shell-fish often come to bear a mixture of fixed organisms on their surfaces. All stationary or slowly moving animals are liable to suffer from this rain of larvae. For example, it is not uncommon to see a crab with several small barnacles on its back, a growth of hydroid, or other sessile animal. This does not matter to a crab. In fact, some crabs (see page 233) deliberately plant such things on their backs. To a starfish depending for its respiration on tufts of skin distributed over the whole of its upper surface, such decoration would be a serious handicap, and the pedicellariae keep the surface clean by picking off and crushing any larvae that may come within their reach.

The starfish we see commonly stranded on the shore possess five distinct arms, but in other species there may be many more than five, while in others the arms are so short that the animal is almost pentagonal.

Class Ophiuroidea
(Brittle-stars)

Brittle-stars keep more to the deeper waters; some have been brought up from depths of nearly four miles, and if by chance one should happen to be left stranded by the receding tide it will bury itself in the sand, or if disturbed, will immediately make for the edge of the water. The arms do not merge into the body, as in a starfish, but are clearly marked off from the central disc of the body. Turned on its back further differences are seen. The grooves so conspicuously present in a starfish are covered in by a series of calcareous plates, through which protrude short feelers, or modified tube-feet. The absence of functional tube-feet alters the whole behaviour and is an excellent example of the vast changes brought about by a comparatively small alteration in one anatomical detail. Without tube-feet another method of locomotion must be found, so the brittle-star moves with wriggling movements of the arms, which are flexible and consist of a series of sections or joints so loosely held together that portions of an arm can be readily thrown off in order to escape from an enemy, a new arm being regenerated in due course. Instead of clinging to the surfaces of rocks during tempests, a brittle-star creeps into crevices. Instead of pulling open shell-fish by sheer force, it must feed on smaller prey, often, especially in the case of those living in deep waters, on the organic debris littering the sea-bottom. The mouth is provided with a pair of 'jaws', often with serrated edges, the so-called 'teeth', not to crush food but to strain it and keep out indigestible matter, and since the stomach is not protrusible a larger mouth must be provided.

The heavily ossified arms preclude the use of breathing tufts like those of the starfish, so at the junction of each arm with the central disc, on the lower surface, there is a pair of slits leading into a respiratory pouch. By the alternate expansion and contraction of the central disc, water is drawn into and pumped from the pouches, a process closely resembling our own method of breathing.


A Brittle-star, showing the serpentine movement of the arms by which it progresses.

The change of habit in the brittle-stars resulting from the loss of the tube-feet is carried a step further in the Euryaleae, or Gorgon-head starfishes, whose arms branch again and again until the end-branches number often tens of thousands, so that the creature comes to resemble a dense coil of snakes. Their habit is to climb up the stems of sea-pens and certain tree-corals and,

Purplish-black sea-urchins *(Centrechinus setosus)* from Australia, with spines up to 10 inches long, on a mass of dead coral. The light spots are five pale blue eyes. They habitually move about in companies with their spines intermingled. Two burrowing clams, *Tridacna*, can also be seen.

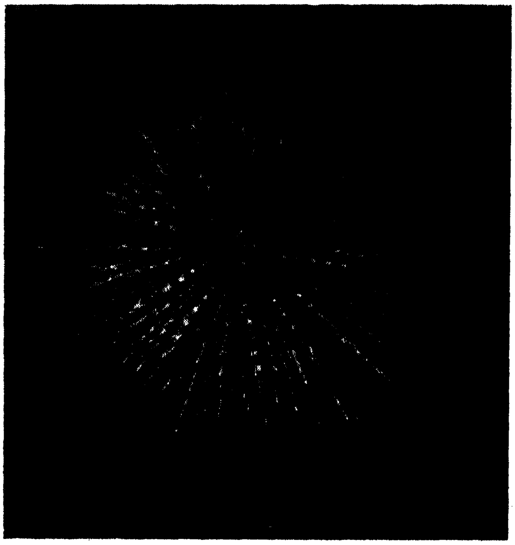
while holding on with some of the branches of their arms, to spread the others out like a net in order to catch any small organisms floating by. To climb, the arms and their branches must move in a vertical direction, winding and coiling upwards or downwards. This is made possible by the curious hour-glass shape of the ossicles supporting the arms.

Class Echinoidea
(Sea-urchins)

Sea-urchins, or Sea-hedgehogs, are most common in shallow waters, and in places abound in large numbers on the shore. The shell is made up of rows of plates closely fitting together, forming a rigid hollow box which may be nearly spherical, heart-shaped or flattened and discoid, the surface being covered with bristling spines. From the mouth, on the underside, protrude five white teeth forming part of an elaborate chewing mechanism, known as Aristotle's lantern.

At first sight there appears little resemblacne between such an animal and a starfish, but both have tube-feet and pedicellariae and if the spines are removed the same radial pattern is seen. The calcareous plates in the skin of the starfish here form a continuous coat, so that a sea-urchin may be described as a starfish in which the arms are withdrawn and the skin covered with spines.

Sea-urchins either bury themselves in the sand or carve cavities in the rock where they can lie up to escape the pounding of the waves. It is believed that the cavities are made by the continual scratching of the spines. Other uses to which the spines are put, in addition to this and protection from enemies, are for resuming the normal position. A Sea-urchin thrown on to its back pushes into the sand with some of its spines, throwing those on the other side over so as to displace the centre of gravity, thus rolling over into the normal position. In the Clypeastroidea or Cake-urchins, the spines are furnished with vibratile hairs which cause a continuous flow of water over the respiratory tube-feet.



A Sea-urchin with the tube-feet extended.
A Sea-urchin seen from the upper side. The slender tube-feet can be seen stretching out beyond the spines. Bare tests are frequently washed up on beaches.

The pedicellariae are used not only for keeping the shell clean but for seizing small pieces of seaweed and holding them over the shell for camouflage. Their other, probably most important, function is as organs of defence, and some are provided with poison glands for this purpose.

The food is animal and vegetable matter, which is masticated by the teeth already noted, but in the Cake-urchins the teeth are used as shovels to scoop up sand, the food being derived from the decaying matter mixed with the sand.

Class Holothuroidea
(Sea-cucumbers)

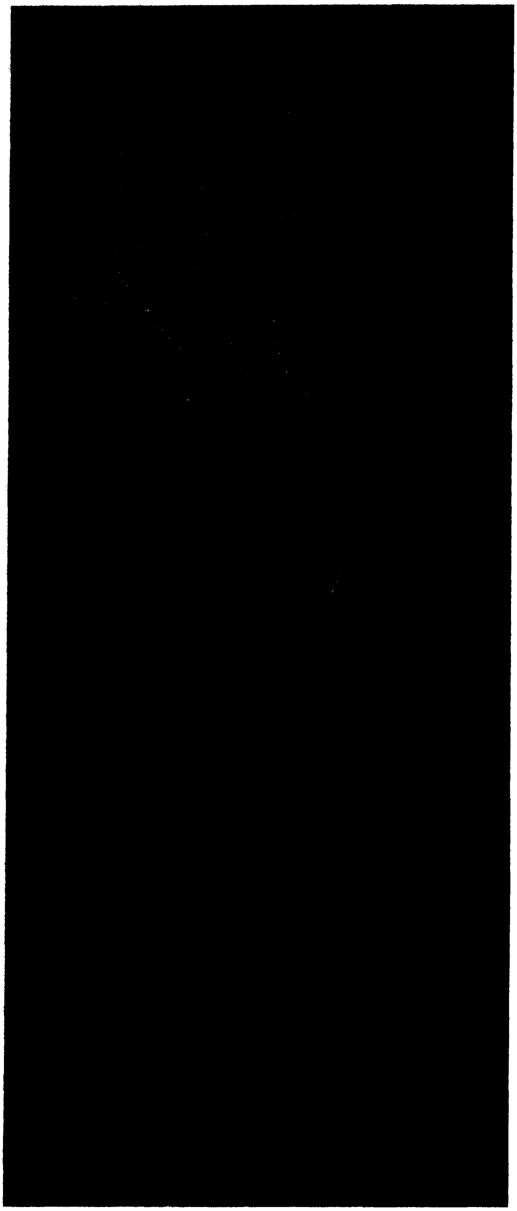
The Sea-cucumbers show yet another variation in the range of form exhibited by the Echinodermata. They are sausage- or worm-shaped, with the skeleton of microscopic spicules embedded in the skin, although in one group, the Psolids, they are modified into large overlapping scales. The mouth is at one end of the body and is surrounded by tube-feet much enlarged and converted into feelers. Even so, the radial pattern is preserved by five longitudinal double rows of tube-feet.

The Sea-cucumber *(Synapta maculata)*, about a yard long, and the brilliant blue Starfish *(Linckia loevigata)*, from the Great Barrier Reef of Australia. Both these animals belong to the phylum Echinodermata, yet one is bilaterally symmetrical and the other radial. At the same time, the starfish was bilaterally symmetrical in the larva stage and the Sea-cucumber is, in fact, secondarily bilateral, there being reason to believe that its ancestors were radial.

A portion of the surface of a Sea-cucumber, showing the tube-feet and the skin supported by anchor and plate spicules. (Magnified 30 times.)

The tube-feet are little used in locomotion. The animals move by the contraction of the body muscles, the tube-feet being employed mainly for holding on to rocks. Food consists either of the decaying matter mixed with the sand, in which case the feelers round the mouth are short and stout to shovel the sand into the mouth, or of small organisms floating about, when the feelers are long and branched and covered with slime in which the prey becomes entangled.

The Holothurians have even greater powers of regeneration than Starfish. If irritated they eject their viscera and regrow a new set in a few weeks. Also, within the body is a set of thread-like tubes which can be shot out at a potential enemy. In the water the slime secreted by these tubes swells out into a sticky mass, so that even a lobster entangled in them may be rendered helpless. These tubes also can be renewed. A few species multiply by tearing the body into two, when each part grows into a complete animal.



The plant-like appearance of the Sea-lily is deceptive. Closely related to the starfishes, it lives in the deeper waters of the sea and feeds on the dead bodies of small organisms which shower down from the surface layers, wavings its arms gently about to catch them as they sink.

Class Crinoidea
(Sea-lilies and Feather-stars)

A Sea-lily consists of a stalk of pentagonal joints, with whorls of appendages, called cirri, at intervals, surmounted by a cup strengthened on its outer side by regularly arranged plates. From the sides of the cup spring five arms which may branch once or many times and which bear a number of side-branches, or pinnules. Down the centre of each pinnule and branch runs a central groove lined with vibratile hairs, and food particles dropping from above are caught and passed on to the mouth. The tube-feet also lining the grooves are respiratory only. Sea-lilies are sessile, the base of the stalk ending in a flattened plate for attachment to a rock, or in a rooting process embedded in mud. The cirri can catch hold of solid objects for support, and if the stalk breaks the cirri are capable of carrying the rest of the body to a new resting place.

Sea-lilies are of great antiquity and many rocks are filled with their remains. To-day they are found in great abundance on the sea-floor from a few fathoms to 2,000 fathoms or more. In the shallow waters their place is taken by an unstalked relative, the Feather-star. It is mobile and while clinging to a solid support with a circlet of cirri found on the undersurface of the cup is able to pull itself along by its arms. Perhaps the most interesting thing is that the Feather-star, free-living in the adult, is at first stalked, the history of its race being repeated in the early stages of its own life.

BEAUTY IN REPETITION

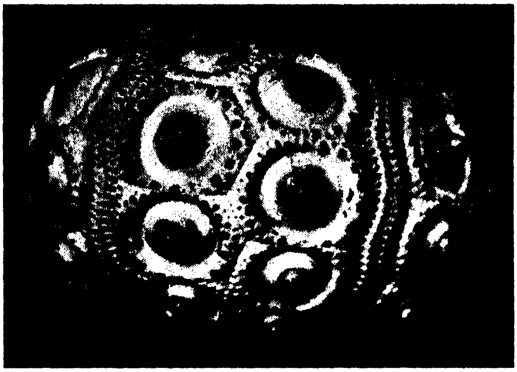
by

DR. D. DILWYN JOHN

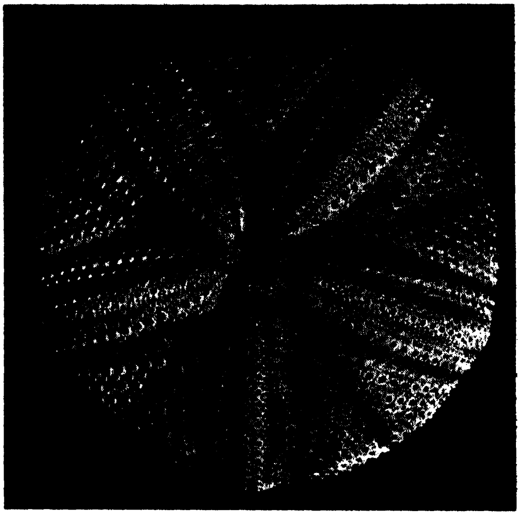
A number of soldiers arranged in column or in line appear more satisfying than the same number in no recognizable order. A long bridge of many arches has more beauty than one of its single arches. And much of the beauty of some natural objects comes from the orderly repetition of parts which are alike.

The grace of many flowers lies as much in the arrangement of petals of equal size and similar shape as in their colour. The same kind of beauty is shown in animals which are radially symmetrical – which have a central point about which the parts are repeated. It is the shape of many which live a fixed life in water, a habit that makes it desirable to offer a similar front on all sides, to have, as it were, an all-round defence. The best known are sea-anemones, which often have the glory of colour added to the pattern of form. But it is found too in some animals which move about, as most animals do, and are for that reason called free-living. The Sea-urchin is an example which repays close study for, the harder one looks, the more order one sees.

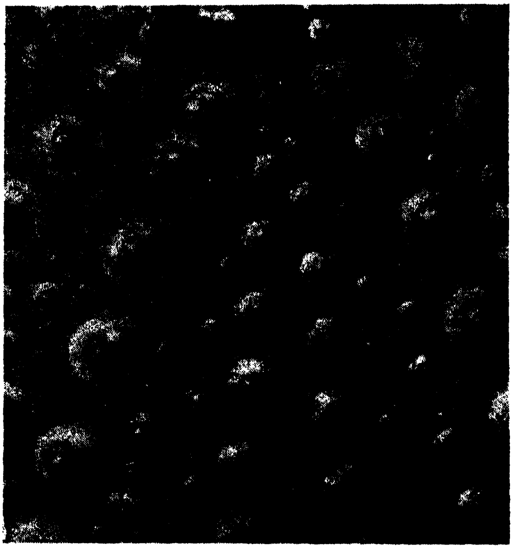
In life Sea-urchins are covered with spines but their bare shells, more properly called "tests", are familiar objects on sea-shores. The first glance shows order. The test is seen to be built up of twenty columns of plates each passing from the mouth at the centre of the underside to the anus at the apex, like meridians from



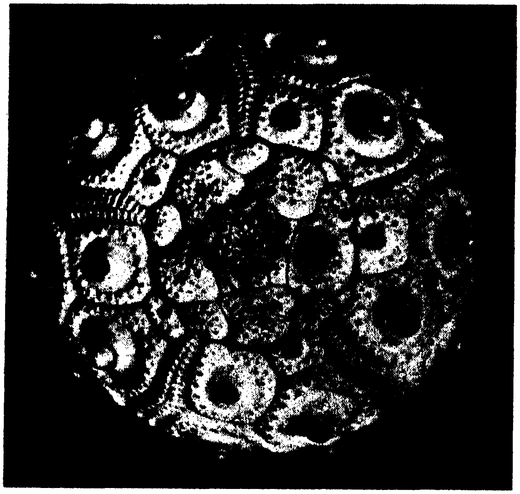
Side view of a Cidarid Sea-urchin showing the pentagonal plates alternating with and dovetailing into one another. The successive plates becoming smaller towards the poles.



Astropyga radiata showing 5-rayed or pentagonal symmetry. A circular sea-urchin with its spines removed to show the bosses on the plates. (One half natural size.)



Strongylocentrus francisarus. Details of the test (or "shell") showing the successive plates becoming smaller, with an effect of heightened perspective.



The upper surface of the Cidarid with the spines removed. Top view of a Cidarid, an example of pentagonal as well as circular symmetry. (Natural size).

pole to pole. The twenty columns are disposed in ten bands, each of two columns, of which five are wide and five are narrow. The narrow and the wide bands alternate. This is radial symmetry; the repetition of similar parts around a common axis like the spokes of a wheel around the hub.

The order goes deeper. If the plates of the wider bands be closely examined each will be found to be pentagonal. The plates of the two columns which compose the band alternate with and dovetail into one another. The plates of each column are biggest at the ambitus, the widest part of the test and become—while retaining their shape—progressively smaller towards each pole. Here again is the repetition of similar parts, but with a new factor introduced: that of a graded change in the size of the parts. Its effect is, as it were, that of a heightened perspective.

The plates are not flat and featureless. They once carried the spines, each of which was attached by muscles to a shining boss. In many forms they are regularly placed from plate to plate and enhance the beauty. Their size varies in proportion to that of the plates.

The plates of the narrow bands present another feature. A lens may be necessary to see it well. They are perforated with pairs of holes. Some species have only one pair to a plate but in others there may be as many as nineteen. If the number is high they are arranged in arcs which lie one above the other as the column passes from the lower to the upper pole. Furthermore, the arcs in the plates of one column are bent towards those of their opposite numbers in the contiguous column. Each of the columns is a complete series of similar parts, expanding in the middle, dwindling to either end. The band comprised by the two columns is a more complete unit, for each column is complementary to, the mirror-image of, the other.

The upper pole shows order of another kind which can be more briefly described. Around it lie two circles each of five plates, those of one circle alternating with those of the other. They are in fact a part of the ten double meridional bands, being each the single plate which terminates one of them.

To summarize: there is first the five-rayed, star-like symmetry; below it is the columned order of the rays, expressed not only by the plates which compose them but by the sculpturing or perforations they possess; and, appearing to surmount the columns, but really a part of them, are plates in circles. Here are three designs—of equidistant radii, of columns and of circles—each intimately linked to the other.

The basic five-rayed symmetry of the Sea-urchin is one it shares with all members of the great phylum to which it belongs, the Echinodermata comprising the Starfishes, Brittle-stars, Sea-

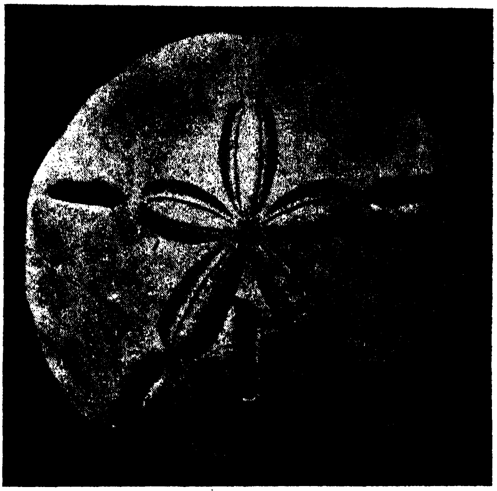
Plagiobrissus grandis, a rare and beautiful species of heart-urchin with its covering of spines. A burrowing form from West Indian waters. (One-third natural size.)

cucumbers, Sea-lilies and Feather-stars as well as the Sea-urchins themselves. Most of them are now free-living but they retain radial symmetry as a legacy from a past in which their ancestors were fixed. But some of them have evolved a bilateral symmetry which is superimposed on the radial plan, the better to fit them for a free life. They may be regarded as striving towards the development of a front end, a head, and left and right sides.

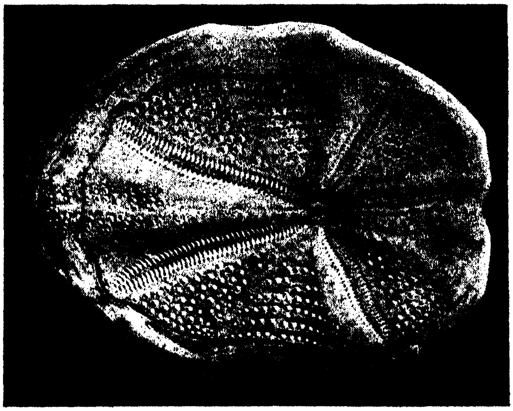
The Sea-urchin we considered was a regular, spherical one. There are others, higher in the evolutionary scale, newer in the pageant of life, which are flat or ovoid and are called "irregular". They have begun to be bilaterally symmetrical. Though the pattern is still dominated by the figure five, it changes. The five rays are not of equal length but become divisible into three parts, two of which are pairs, one pair different from the other, and the other an unpaired ray. Though the more geometrical symmetry of the regular forms is lost, a newer and freer kind of beauty may be introduced. It is so in the flat Sand-urchins not present on British coasts but widespread in warmer waters. The narrow bands of plates—those with pairs of pores—are so arranged on the upper surface as to form a flower-like design. There may be deep indentations into the margin of the test, or a number of lunules, or slits, cut through it. They are always symmetrically arranged and may be five in number.

A Heart-urchin (*Echinocardium cordatum*) is commonly washed up in large numbers on sandy shores. It is the size of a small potato, is covered with short spines and is grey. The denuded or cleaned test reveals bilateral symmetry similar to that described above, but the pattern is not so pleasing. If however the plates of the thin-walled test be closely examined, preferably with a lens, unsuspected patterns and order come to light emphasizing the bilateral symmetry. They lie in the nature and arrangement of the spine bosses, and they imply bands and areas of very different spines.

Many more examples of the repetition of similar parts in man-made objects are to be found in architecture, in avenues and formal gardens, in the groupings of ships and of planes. But the same device may surely be found in arts which appeal not through the eye. In poetry what else are rhythm and rhyme themselves? The measured repetition of a sound (rhythm and rhyme combined) has of itself a mysterious power to please.



The Sand Dollar from the shallow waters of the eastern seaboard of the U.S.A., *Mellita quinquisperforata*, a flattened disc-shaped sea-urchin showing a petal-like pattern and lunules (or slits) and a bilateral symmetry. It has a front end and a hind end, unusual in sea-urchins, and the five narrow bands of plates on the upper surface disposed in a flower-like pattern. (Natural size.)



Plagiobrissus grandis with its spines removed to show the bosses. (One-third natural size.)

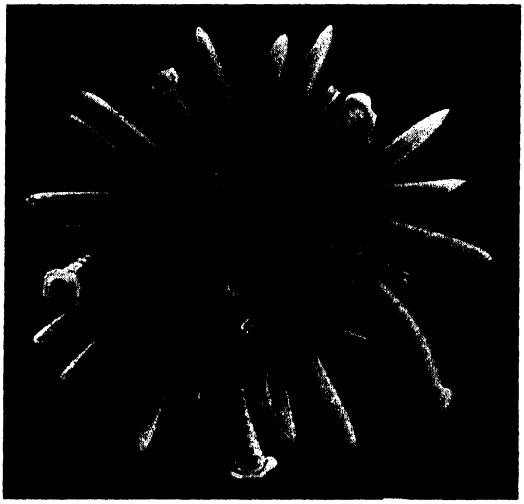
ON THE PROPAGATION OF ECHINODERMS

by

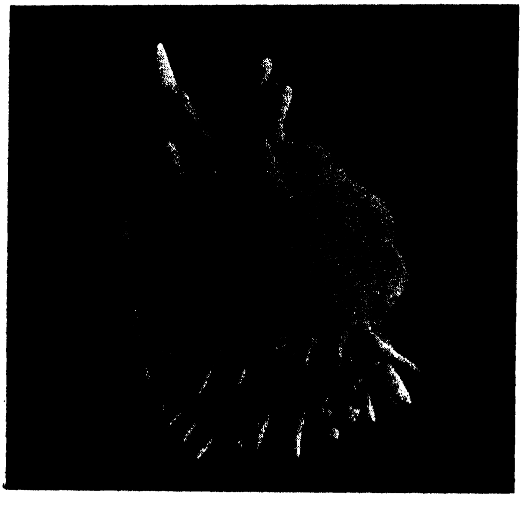
DR. T. MORTENSEN

From the time nearly a century ago when naturalists began to study the embryology of marine animals, the Echinoderms, particularly the sea-urchins, have been among the favourite objects for such studies. The eggs of all our common sea-urchins are small, only 0.1 to 0.5 mm. diameter, and quite transparent. No copulation takes place, eggs and sperm being simply shed in the water, the spermatozoa thus having to swim about and find the eggs. These facts combined make the sexual products of sea-urchins particularly fit for microscopical examination; the whole process of the fertilization is easily followed: the penetration of the spermatozoon into the egg, the fusion of the two nuclei, that of the egg and that of the spermatozoon, through the complicated process of "mitosis", the cleavage of the fertilized egg, etc. It was, indeed, mainly through the study of sea-urchins' eggs that the great secret of fertilization was discovered, only about half a century ago.

A further marvellous property of the eggs of Echinoderms (and many other marine animals) has given rise to a special branch of science during the last half-century, experimental embryology. If the two cells into which the egg first divides are isolated, each will develop into a complete larva, only half the normal size. In the 4- and 8-cell, or even later, stages the cells can be isolated. Thus it is possible by direct experiment to ascertain what role each cell plays in the development, to which organs it gives rise, and so on. In nature similar experiments may occur. Thus I found in studying the development of a sea-urchin living in the Red Sea that in a considerable number of the developing eggs, some 10 % or more, the two first cleavage cells remained isolated (within the egg membrane), each developing into a normal larva, only half-size We have here a case of one-egged twins, as occurs now and then in some other animals, even in man.



The further stage in the development of a sea-urchin, with the rounded body and radial symmetry shown by the five tube-feet. (Magnified 50 times.)
(*By courtesy of G.B. Instructional Ltd.*)

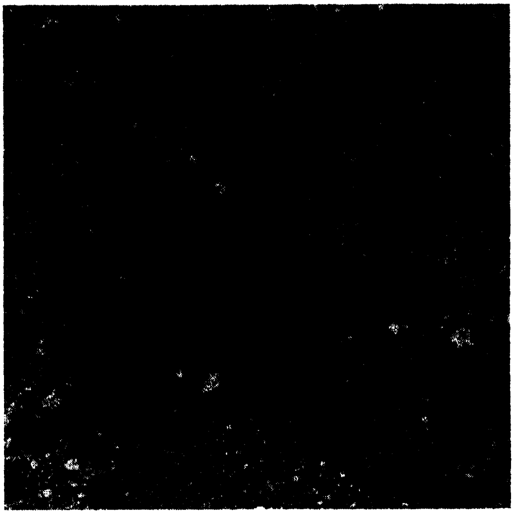


The young sea-urchin, highly magnified, beginning to take on the tube-feet and spines of the adult. (Magnified 50 times.)
(*By courtesy of G.B. Instructional Ltd.*)

After fertilisation the egg develops into a free-swimming larva, of very characteristic shape, entirely unlike the adult. The shape of the larvae differs in the various classes of Echinoderms, and are named accordingly Bipinnaria (sea-star larva), Ophiopluteus (brittle-star larva), Echinopluteus (sea-urchin larva), and Auricularia (sea-cucumber larva). Only the sea-lilies have, so far as is known, no larva specially adapted to a pelagic life. The Ophiopluteus and Echinopluteus have an exquisite skeleton supporting their long arms. Generally the larvae swim only by means of cilia, arranged in bands along the arms or processes of the larval body; but a few of them perform active swimming movements, as for example, the very peculiar, larvae of the sea-urchin *Diadema*, its two long arms being moved by an elaborate muscular system. Also the larvae of the sea-star *Luidia Sarsi* swims actively by means of its two long median lobes.

The transformation of these free-swimming larvae, of typical bilateral shape, into the (usually) 5-radiate, bottom-living adult Echinoderm is no less remarkable than the metamorphosis of a caterpillar into a butterfly. The process of transformation is exceedingly complicated, and during the process the young sea-star is formed on one side of the posterior end of the larva. As a rule the body of the larva is absorbed by the developing Echinoderm, but in *Luidia Sarsi* the young sea-star detaches itself from the larval body and sinks to the bottom, the larval body continuing to swim about for some time, ultimately to perish. The same is the case with the brittle-star *Ophiothrix fragilis*. In a similar larva from the West Indies it would appear that the thrown-off larval arms are able to regenerate a new larval body but this has not yet been definitely ascertained. Such is the usual way of propagation in Echinoderms. But there are many modifications.

Ophionotus hexactis, a brittle-star, in which the embryos develop inside the ovaries. The photograph shows the underside of the disc, with the mouth at the centre, and the five pairs of bursal slots, at the bases of the arms, through which the young ones leave the parent.



Henricia sanguinolenta, a starfish which broods over its young. (Natural size.)

In several forms the eggs are rather large, about 1.0 mm. diameter, and full of yoke. They do not, as a rule, give rise to a true pelagic larva, but to a small worm-like body, which transforms directly into the Echinoderm. Several sea-stars laying such large eggs collect them in a cluster around the mouth, the mother animal raising its body on the arms so as to form a well-shaped space in which the brood is kept till the young ones are able to take care of themselves. This is the case, for example, in *Henricia sanguinolenta*. The animal can of course take no food so long as the brooding goes on, some weeks at least. In a few cases the eggs are even taken into the stomach and hatched there; it is not easy to conceive how the stomach can be set entirely out of function, so that the eggs and embryos are not digested.

A good number of species, particularly among the brittle-stars, are viviparous, the young ones being hatched within the so-called 'bursae', a couple of pouches situated at the base of each

A group of starfish, *Archaster typicus*. Although it is evident from their habits that there are, contrary to the usual condition in starfish, both males and females, there is nothing in their outward appearance to indicate the sexes. (One-third natural size.)

arm, normally serving respiratory purposes, but here being used as brood-pouches. In these cases the pelagic larval stage is of course eliminated; still traces of the pelagic larval form are sometimes found, for example, in the cosmopolitan brittle-star, *Amphipolis squamata*. A most unusual case is that of an Antarctic brittle-star, *Ophionotus hexactis*. Here the embryos are hatched not within the bursa but in the ovaries themselves (which are attached in a series along the inner wall of the bursa). Of the number of eggs found in each ovary only one develops, using the other eggs for food. The young one grows to a very considerable size and gradually widens the ovary so that it forms a large, thin-walled sac. It is almost inconceivable how these large young ones can get out of the narrow bursal slots; this holds good of many other viviparous brittle-stars. In cases where the number of young ones developing within a bursa are more numerous, they are jammed together in the most extraordinary way, in spite of their hard calcareous skeleton, recalling strongly wrinkled dried peas. It is almost incredible how such young ones, when liberated can assume the normal regular star-shape.

Generally it is impossible to distinguish the male and female Echinoderms except by opening them and examining their genital organs. But again here we find a few interesting exceptions. A sea-star very common on sandy ground in shallow waters of the Indo-Pacific region, *Archaster typicus*, exhibits a sort of copulation, the male lying on top of the female, their arms intercrossing, so that it looks like a 10-armed star. Still, externally no difference between the two sexes is observable. The same obtains in an Antarctic brittle-star, *Astrochlamys brunneus*. But a much more interesting case is offered by a couple of species of small brittle-stars of the Indo-Pacific region, which live as commensals on or under sea-urchins. The great French specialist in Echinoderms, R. Koehler, was the first to describe one of these species which he named *Ophiodaphne materna*. He found it constantly carried a much smaller specimen on its mouth, the arms of the small specimen interweaving with the arms of the larger specimen. Very naturally Koehler thought the small specimen to be a young one, thus taken care of by its mother in this quite pathetic way, and so he named the species *materna*—the motherly one. The present author, however, found the small specimen to be the male, carried constantly around by the female—which is thus anything but a careful mother. The eggs are, as usual in brittle-stars, shed directly into the water, and the young ones thus left to take care of themselves, the mother living in a constant embrace with its lover.

Astrochlamys brunnea, the brittle-star. There are two groups of brittle-stars, those in which the arms can be moved laterally, and those in which they can be moved up and down, resulting in the serpentine coiling shown here. (One-half natural size.)

CHAPTER XI

ANIMALS OF UNCERTAIN ORIGIN

THERE are some animals the names of which everybody is familiar with even though they may not necessarily know the animals themselves. On the other hand, there are those most people are familiar with but do not necessarily know their names. There is, however, a third group of which most people not only have no knowledge but may not even have heard their names, yet they are animals which have an important part to play in the living world, and are in addition of considerable scientific interest. Two members of this third group are the Polyzoa and Brachiopoda, neither having a very close relationship with the other, but dealt with together in this chapter because it is impossible to place them more accurately in the system of classification; and also because they share with each other the character of being little-known and neglected phyla.

Phylum Polyoza (or Bryozoa)
(The Moss Animals and Lace Corals)

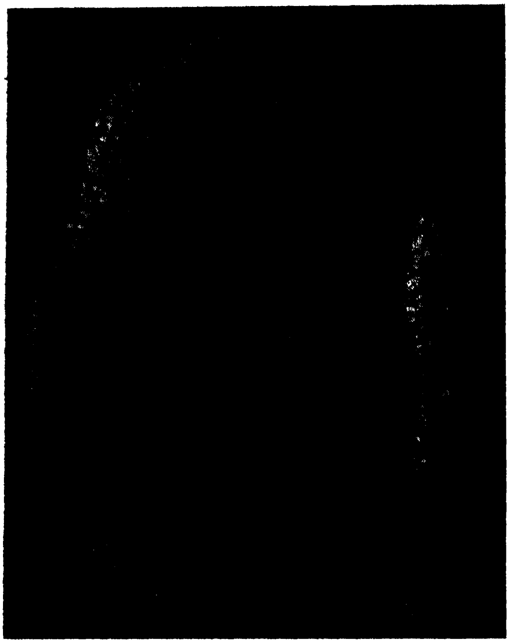
General characteristics

The Polyzoa, or Bryozoa, are mainly marine, with a few freshwater species, and with one exception form colonies which encrust stones, shells and seaweeds, or are tree-like, fan- or cup-shaped. Each colony consists of a number of separate chambers in a common investment, each chamber being inhabited by a polypide of simple structure with a well-formed digestive tube and bearing a crown of tentacles around the mouth. Reproduction is by a ciliated larva, and the colonies grow by a vegetative budding of new polypides.

On almost any shore throughout the world these curious animals will be found, either cast up with the seaweeds in the drift-line, and looking very like seaweeds themselves, or forming delicate patches of minute, lace-like appearance on the seaweeds, or as branching or finger-like gelatinous masses, or at low tide forming lace-like incrustations on the rocks. Those growing in the deeper waters often form masses of considerable size and look like some form of coral, whence the name Lace Coral. The other alternative names also give a clue to the appearance of the more typical forms: Polyzoa, because they are made up of many animals living together, and Bryozoa (literally Moss Animals) because they encrust the rocks in the sea in much the same way as the moss plants encrust the rocks on land.

A large colony of the Polyzoan, *Flustra foliacea*, commonly called the Sea-mat, abundant on the shores of Western Europe. It is usually mistaken for a seaweed. (One-third natural size.)

A few species are also found in freshwater, and one of these has a sufficiently simple form to



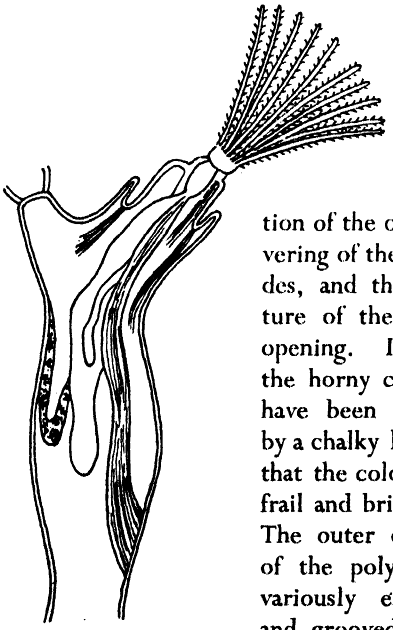
A part of a branch of *Flustra* enlarged to show the colony formation, or series of chambers, of which each such colony is composed. Each chamber contains a polypide. (Magnified 5 times.)

serve as a pattern by which the more complicated marine species can be understood. This is *Paludicella*, found in the rivers and lakes of Europe. It consists of a number of animals, referred to as polypides, or polyp-like animals, since they bear a superficial resemblance to the polyps of corals and other Coelenterates, and yet differ markedly from them. Each polypide lives in an elongated chamber of a tough, horny material, and is joined to its neighbours at either end. In this way a small moss-like growth is formed, the branches of which consist of rows of polypides placed end to end.

Each chamber bears an opening near the front or upper end, through which the polypide protrudes its mouth surrounded by a ring of hollow tentacles. The rest of the body remains permanently inside the chamber. The most conspicuous organ is a U-shaped digestive tube composed of a muscular pharynx immediately below the mouth, a stomach and a short intestine which reaches up to open to the exterior near the mouth. At one point this tube is fastened to the body-wall by a double strand of tissue, the funiculus. There are no blood-vessels, the functions of a blood system being taken over by a clear, colourless fluid filling the body-cavity, the space between the digestive tube and the wall of the chamber. There are no sense organs and the nervous system consists of a small collection of nerve-cells near the mouth.

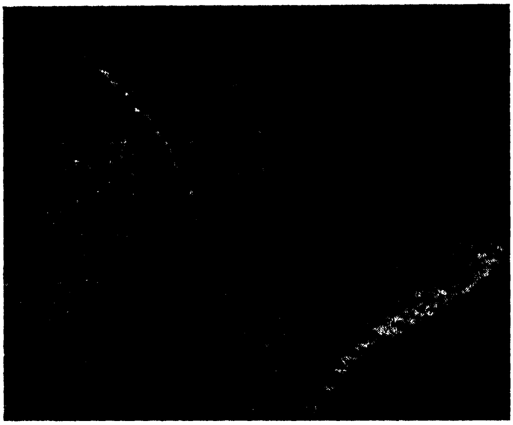
Where the funiculus joins the body-wall are two masses of male and female reproductive cells. The eggs remain in the body-cavity after fertilisation. Eventually the ciliated larvae escape into the water, swim about for a while and settle down to form fresh polypides. Each new polypide starts a fresh colony by repeated budding. There is thus an alternation of reproduction by sexually-produced larvae and of the purely vegetative growth.

Except that the marine species build bigger colonies, they differ little from *Paludicella*, and the main differences between them concern the shape of the colony as a whole, the ornamentation of the outer covering of the polypides, and the structure of the mouth-opening. In some the horny chambers have been replaced by a chalky layer, so that the colonies are frail and brittle.



Drawing of a Polypide of *Paludicella* in its horny chamber, showing the crown of tentacles surrounding the mouth, which leads into the U-shaped gut. The shaded bands are the muscles which retract the tentacles.

The outer covering of the polypides is variously embossed and grooved, giving delicate and beautiful patterns of microscopical proportions. This ornamentation is often such as to give the enclosed ani-



The ends of some fronds of seaweed encrusted with a Polyzoon, *Membranipora pilosa*. (Magnified 5 times.)

mal a certain amount of protection, while many of the mouth openings are protected by small groups of blunt spines, and in a few there is a definite lid, or operculum.

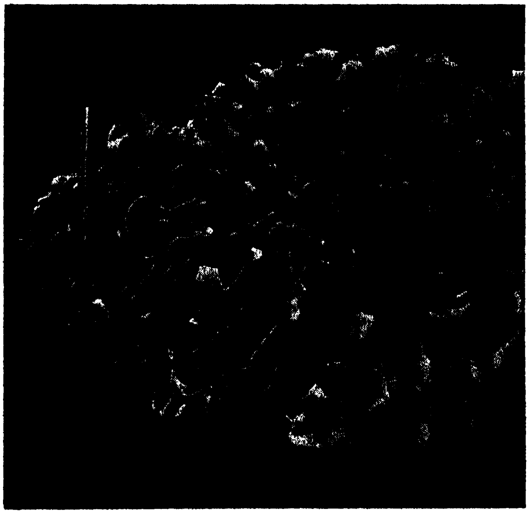
In some species a number of the polypides have become modified to form avicularia, or "bird's-head organs". These have the appearance of minute vulture's heads mounted on slender necks, the beaks of which snap viciously at anything coming within their reach, as they sway gently backwards and forwards. In other species long, whip-like vibracularia are present. Both these structures probably help to keep the colony clean by preventing sediment from settling on the surface.

All the Polyzoa are sessile except the fresh-water *Cristatella*, in which the colony, flattened and slug-like, with the polypides projecting all over the upper surface, is able to move about over the stems and leaves of waterweeds by wave-like contractions of the undersurface.

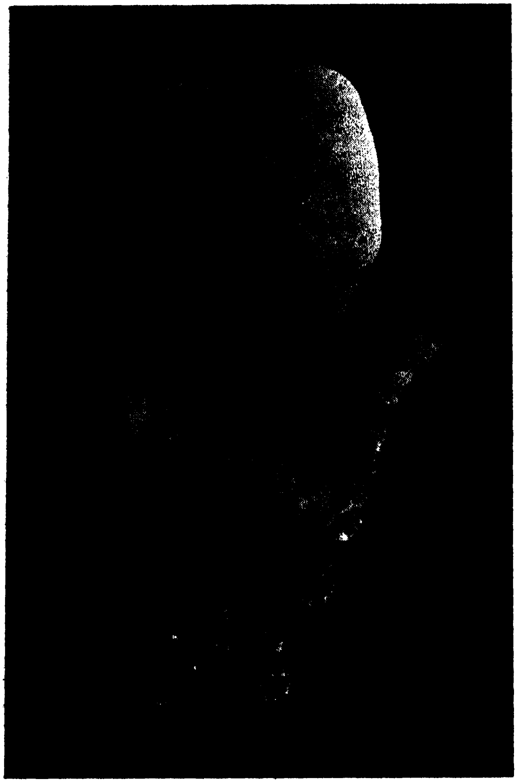
Phylum Brachiopoda
(Lamp Shells)

Relics of bygone days

Just as in human beings there are individuals who, once these have become set, cannot be persuaded to change their habits, while others are more enterprising and are prepared to try new ventures and new ways of life, so we may distinguish between species of animals that are enterprising and those that are not. But whereas the life-time of a human individual is at the most a hundred years or so, the lifetime of a species has to be reckoned in tens of thousands of years, or even tens of millions. Consequently, it is easy to see and note the changes in habit in a human individual but difficult to trace the changes in species. There are some species which we may call young and enterprising, such as the starling (*Sturnus vulgaris*) which has increased its range in Europe in the last hundred years and which, when introduced into the U.S.A., spread rapidly across the continent. Such species are marked by an unusual variability in form and a versatility of habit; they tend to increase rapidly and to spread out over a wider territory. It is as though, in the first flush of youth, they are full of vitality, resource and initiative. There are, on the other hand, those of set habits and constant structure but of restricted range, the stay-at-homes, as it were. Generally speaking, the enterprising species have a short life and a gay one, if we may speak of them in such human terms, while the others plod on, never achieving much, but lasting for a long time. The geological record is full of examples of the two kinds: those that reach



Lepralia foliacea grows in several fathoms. It is hard, but very brittle. Its size may be judged by the fountain-pen on the left.



A recent Brachiopod seated on a fragment of coral, showing the stalk by which it is attached issuing from the "spout" of the shell. (Natural size.)

their peak in a short while, in tens of thousands of years, flourish exceedingly, and die out as quickly as they came; and those that take a long time to reach their peak – say tens of millions of years – an unambitious peak which they maintain unaltered for a long time, and then as slowly die out. A good example of the latter is the King Crab (see page 64).

The contrast seen in the growth, behaviour, and length of life of species is seen also in genera, families, orders and phyla, and the particular phylum we have to deal with now belongs to the second group, the conservative, long-lived type, for the phylum Brachiopoda have preserved their main structural plan intact throughout a long evolutionary history. Representatives of this phylum are found in the oldest fossil-bearing rocks of the Lower Cambrian and some of the genera that appeared then have persisted almost unchanged down to the present day. Moreover, fossil Brachiopods are present in the rocks from that remote time onwards, and may be found in large numbers, especially in certain of the strata. Here then we have animals which have persisted almost unchanged for over five hundred million years, whose fossil remains are abundantly present in the rocks, but whose representatives living to-day are of uncommonly scanty occurrence. It is not surprising, therefore, that their relationships with other animals should be obscure.

General characteristics

Brachiopoda are sessile marine organisms with the soft parts enclosed in a bivalve shell, one of the valves being larger than the other and having a rostrum through which runs a stalk, or peduncle, by which the animal is attached. Within the shell the body occupies the hinder part of the mantle cavity. The mouth, which is ventral, is overhung by a horseshoe-shaped disc, or lophophore, with two elongate or coiled, tentacle-bearing arms covered with cilia. There are a heart and a few blood-vessels, a simple nervous system, but no sense-organs. The sexes are separate. Food consists of small organisms drawn into the mantle cavity by the vibratory cilia of the lophophore. Reproduction is by free-swimming larvae, but in some species development takes place in a special brood-chamber within the mantle cavity.

The Brachiopoda are known as Lamp Shells because of their resemblance to the ancient Roman lamp. In describing them it is inevitable that reference should be made to the fossil forms, for all that is left of a flourishing group of over 2,000 species is a few families containing 140 species. Most of them are found at depths down to 100 fathoms, but some are found as deep as 3,000 fathoms.

Few people have had the opportunity of seeing living Brachiopods, though reference to one of them, *Lingula*, will be found in books on natural history, since they do not form part of the familiar beach fauna. They are very like Molluscs in outward appearance, and for many years were classed with them. At other times they have been treated as Annelids (Worms);

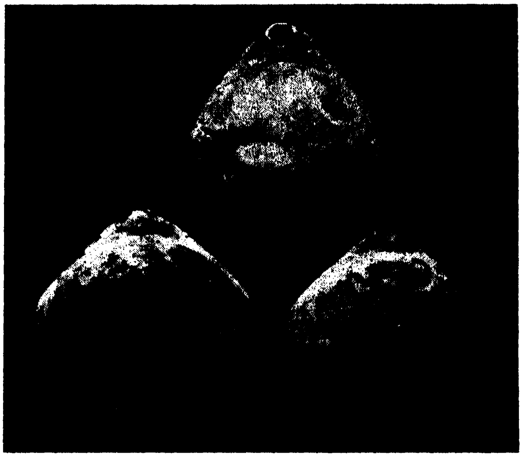
and, finally, it has been suggested that with the Polyzoa and other forms, *Rhabdopleura* and *Cephalodiscus*, usually treated as degenerate Chordates, they should form a separate phylum known as the Podaxonia. None of these views has been widely accepted, and it seems that a better knowledge of their embryology is required before their relationship to the other Invertebrata can be decided.

Although so very like a bivalve Mollusc, there is one fundamental difference by which the Brachiopod can be recognised, apart from the more obscure details of the internal anatomy. In the Mollusc the two parts of the shell are lateral, whereas in the Brachiopod they are dorsal and ventral respectively. In the anatomy, although there is the same mantle for secreting the shell, the arms comprising the lophophore, which were originally supposed to represent the foot of the Mollusca, consists of extensions of the mouth. In conclusion, then, it may be said that while these two groups of animals are related, but distantly, they have a superficial resemblance to each other which is the result more of a convergent evolution.

Although the rest of the living members of the phylum are permanently fixed to some solid object, *Lingula* is not fixed permanently to the sea-bottom, but lives in a tube of sand. Inside this it can stretch its shell upwards to the aperture of the tube so as to take water into its mantle cavity. When it is disturbed, however, its peduncle contracts and withdraws the shell back into the tube. (One half natural size.)

Degeneration in evolution

Is is appropriate at this point, and in this connexion, to revert to the meaning of the word evolution. Broadly speaking, evolution is a particular kind of change, one in which there is an unfolding of related events in a natural and orderly sequence. There are two fundamental misconceptions often held, which make for much confusion of thought. The first is that evolution is something that applies only to living organisms, whereas all change – or we could use the word development – implies an evolution, whether concerned with natural or man-made things. The second mistake is made in the assumption that evolution connotes progress, in the sense of change from a simple to a complicated form, from the inefficient to the efficient, and so on. On the contrary, evolution may, and often does, mean retrogression or degeneration, and there are many examples of species, of both animals and plants, where continued evolution has led to degeneration.


A recent Brachiopod, with two fossils (below), showing how little the form of these animals has changed over long periods of time. (Natural size.)

In both the Polyzoa and the Brachiopoda we have, apparently, examples of degeneration, and more especially is this so with the first of them, where there is so marked a plant-like form, comparable with that of the lower invertebrates such as sponges and certain Coelenterates. Yet in both of them there is a well-developed gut, suspended in a body cavity, a heart and blood-vessels, together with other ill-defined viscera, comparable with those of the higher invertebrates and the lower vertebrates, yet showing all the signs of having become secondarily less complicated.

Having said this much, which reflects the usually accepted point of view, the fact remains that there is a lack of the usual evidence to support the theory. For example, the Brachiopoda, recognisable as such, are among the oldest recognisable fossils and have come down to us almost unchanged. There is, therefore, practically no evidence for regarding them as degenerate; or, if they ever reached a higher point of organisation, then such attainment must have coincided with the formation of some pre-Cambrian rock in which all traces of fossils have been obliterated. As to the Polyzoa, the position is much the same, though the circumstantial evidence in favour of a degenerative trend having been followed is strong. The linkage in an animal of larval characters and a digestive system comparable with those of Mollusca, with the general form of the plant-like lower invertebrates, suggests a degeneration which is perhaps better interpreted as a specialisation, accompanied by retrogression, in the direction of a secondary simplification. While it is neither possible nor desirable to go into greater detail here, sufficient has been said to show the obscurity surrounding the relationships of some animals. Mysteries which will probably never be solved, yet which remain fascinating, are offered in this way.

Gemmules and Statoblasts

In many freshwater Polyzoa, special reproductive bodies, known as statoblasts are formed. These consist of groups of unspecialised cells surrounded by protective coats. Statoblasts will survive both the drying up of streams and the intense cold of winter, and have an obvious survival value for organisms living in ponds and streams. Under favourable circumstances of temperature and humidity, the living contents of the statoblast flow out and found a new colony.

A similar device is found in freshwater sponges, where a reproductive body essentially the same as that of Polyzoa is produced. It is, however, usually known as a gemmule, or little bud. The fact that one is called a statoblast and the other a gemmule has an historical significance only and is an example of the unnecessary confusion, all too common in biology as in other subjects, resulting from a lack of uniformity in technical terms.

Other freshwater animals, such as the waterfleas among Crustacea, produce winter eggs with special protective coats to withstand the cold and the effects of desiccation.

THE ANIMAL AND ITS SURROUNDINGS

by

DR. BEN DAWES

Multicellular animals, or Metazoa, are dubitable derivatives of the Protozoa, but the manner of their derivation is doubtful. Possibly the unicellular ancestors of Metazoa developed internal cell boundaries or, as seems more probable, their nature was from the start colonial. Protozoan colonies exist in a variety of forms, linear, discoidal, spherical and arborescent, and from some such forms as these the metazoan body may well have been derived. Haeckel's conception of a hollow *Volvox*-like colony of flagellate individuals seems to be as likely a starting point as can be postulated. If this conception is correct, then the cells must have been at one and the same time locomotor, protective, sensory and nutritive. The animal's component cells were unspecialised and there was no division of labour between them.

Perhaps the first cells to be separated off from the rest for the performance of a special function were given the task of digesting and absorbing food. At any rate, one of the first stages in the differentiation of the Metazoa was the development of two layers of cells, one forming the outer surface of the animal and the other lining the central cavity; and it seems likely that a mouth, or opening leading into the inner chamber, was developed contemporaneously or after a comparatively short time, for it is very unlikely that holozoic feeders could have made much evolutionary progress with an enteron but no means of ingress to it. Animals having this type of structure are said to be *diploblastic*, two primary layers of cells alone being concerned with their development and perfection. The *Hydra* goes far beyond this primitive condition, some of the cells comprising its body having become specialised for a variety of tasks, and there are many other Coelenterates which show greater specialisation than *Hydra*. Most Metazoa went far beyond this type of structure and many attained a far greater size. Many Protozoa are microscopic, but not all of them. *Monocystis* shows up like a speck to the naked eye, the ciliate *Bursaria* is one eighth of an inch long and *Nummulites* is about one inch in diameter. Such large Protozoa as these are not more complex than their smaller relatives, but a larger size in animals generally denotes greater structural complexity. This rule obviously does not apply to animals of one and the same kind, for a mouse is not less complex than an elephant, but the smallest vertebrate is invariably larger than the smallest worm, and this in turn is larger than the smallest protozoon. Complexity of structure depends largely on hereditary constitution, and this permits wide variation in size within certain limits for every class of animals, but the position in the scale of sizes depends on the degree of complexity attained by animals of a particular class.

Extremes of size have both advantages and disadvantages. Aquatic animals of small size run a greater risk of being swept into unfavourable situations by water currents. Jelly-fishes are often left stranded on the beach by an ebbing tide, while sharks do not so easily become castaways. On land a small size implies slow translatory movements of restricted range. The legs of a caterpillar serve very well for most purposes, but they are no match for the squirrel's legs if a country road has to be crossed in front of an approaching car. Small animals are often persecuted by larger animals, to be pursued, killed and eaten, and only rarely is the converse true. Increase of size entails greater powers of capturing prey, and better chances of escaping predators. Perhaps the biggest advantage that a large size has to offer, however, is the greater independence that the animal gains over the conditions in the outer world. The external environment is always exacting because it comprises a set of conditions which are not precisely those necessary for the continued well being of protoplasm. By increasing its size an animal takes the first step towards emancipation from the environment, protecting itself against extremes of temperature, desiccation or waterlogging, and perhaps many other threats. It is also better able to store nutrients inside its body, and the chief drawback of the larger size attained is the loss of effective surface with which to make contact with the outer world, whence come beneficial as well as

A North American slug, showing the breathing aperture and the stalked eyes. Small size in animals implies both slowness of movement and persecution by larger animals.

baneful things. In a cluster of cells, those nearest the centre will be least favourably situated, for they risk starvation of food and oxygen that can only be obtained from outside, and they run a serious risk of damage by accumulated waste materials. These risks are lessened if the cells be confined to the surface of a hollow mass. If the cell-cluster be invaginated, or pushed in on one side, to form a hollow sphere open to the exterior, conditions are further altered for the better. All the cells may then be equidistant from the surface, which is at the same time vastly increased. By some such method as this metazoan animals have offset the handicaps of a large size and have increased their effective surface. The central chamber serves well for the reception, digestion and absorption of food, the opening serves as a mouth, and the external surface can be absolved from all duties except protection, support and sensory activity.

Triploblastic animals. The diploblastic type of organisation entails comparatively slow transport of nutrients, respiratory gases and excretions by diffusion from cell to cell throughout the animal. It serves very well even in some very large and watery jelly-fishes, but it is an unsuitable arrangement for large land animals, and in all animals more highly organised than the Coelenterates it has been superseded by a type of structure that is based on three primary layers of cells instead of two. The third layer is the *mesoderm*, which replaces the mesogloea of the Coelenterate and like this is interposed between the endoderm and the ectoderm. Animals having this type of structure are said to be *triploblastic*.

The origin of the mesoderm was an important step towards the enrichment of the world of animal life, making possible a wide variety of structure, for this layer of cells not only forms many of the internal organs of higher Metazoa, but it also takes part in the elaboration of organs primarily composed of ectoderm or of endoderm. In flatworms the mesoderm exists in its simplest condition, forming a spongy packing tissue (*parenchyma*) between the integument and the internal organs. Nevertheless, in this tissue definite layers of contractile fibres have replaced the muscle-cells of the *Hydra*. The muscular system has already become separated from the integument. In the meshwork of the parenchyma there is a watery liquid into which nutritious substances can diffuse from the gut and can be distributed throughout the body by ebb-and-flow circulation due to the muscular movements of the worm. A rudimentary transport system has already been attained. Some large land planarians must have reached the upper limit of size at which such a simple system will satisfy the needs of the body. In all more highly organized Metazoa more efficient means of transport have arisen as a result of the splitting of the mesoderm into two main layers, one associated with the integument and the other with the gut. Between the two layers a large space or coelom has appeared, and in this lie various internal organs, each with a thin wrapping of mesoderm. The appearance of the coelom was the signal for much greater increase in total size than had been attained previously, and further elaboration of the architecture of the animal's body. Essential substances had to be transported greater distances, likewise unwanted waste materials; the problems of co-ordination of movements and other physiological functions were enhanced and larger and better receptors and effectors became a necessity. Better translatory movements made possible more extensive excursions and secured a choice of more varied food, entailing elaboration of the digestive system. Some of these elaborations concerned the ectoderm and endoderm alone, but many of them would have been impossible without the help of mesoderm, which contributes to the deeper parts of the skin and forms the internal skeleton of all vertebrates and some invertebrates, the muscles of the body, the gonads and the sex cells, the heart and blood vessels and blood, the wall of the coelom and excretory organs such as the kidneys of the vertebrates. Because of the elaboration of the mesoderm the body became more diversified and efficient, enabling the animal to become much larger without sacrificing itself to an aquatic life, as a giant jelly-fish must do.

It came to have more kinds of cells and organs, and an altogether higher grade of organisation.

CHAPTER XII

PHYLUM MOLLUSCA

The soft-bodied shellfish and all their relatives

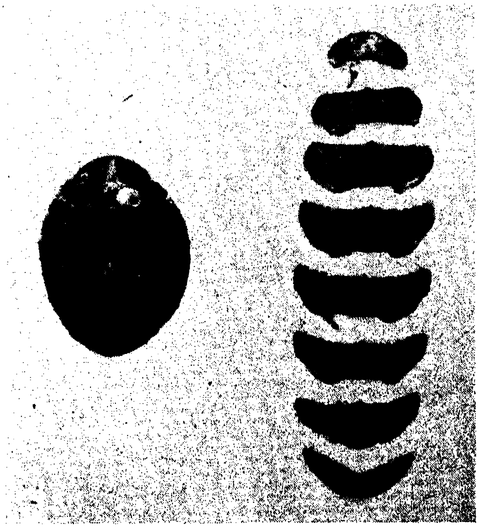
TYPICALLY a Mollusc is a soft-bodied animal enclosed in a shell, but in so many the shell has become modified, reduced in size, or lost altogether. In some the shell is not external but, being reduced, has found its way inside the body, as in the well-known cuttlebone. Side by side with this, there have been considerable modifications in the form of the body itself, some of them being of an extreme nature. Consequently, although everyone is familiar with them as snails and slugs, or as a result of eating winkles, cockles, whelks, oysters, mussels and clams, and has a general idea of what constitutes a mollusc, it is not easy to frame a brief definition of the group as a whole and yet include the many departures from the typical form and appearance.

General characteristics

The Mollusca are world-wide, living on land, in the sea and in freshwater. They are mainly vegetarian although a number of them are carnivorous.

The name, derived from the Latin *mollis* or soft, gives the clue to the chief characteristic of the Mollusca. The body is soft, but is protected by a hard, limey shell except where this is secondarily lost, and consists typically of a head, often ill-defined, a mass of viscera overlaid with a mantle which secretes the shell, and a muscular foot.

All Mollusca, except the Lamellibranchia, feed by means of a radula, a chitinous ribbon bearing numerous, usually minute, teeth. Moved by special muscles this slides backwards and forwards over the odontophore, a special protrusible part of the floor of the mouth. The movement of the radula not only tears up the food but draws it into the mouth. The posterior end is contained in a narrow, curved pouch, the radula sac, and as fast as the front end is worn down by use the loss is made good by growth forward from the root. The possession of a radula is a distinctive character of the Mollusca as a whole and its size, shape and pattern is distinctive for each species.



A Chiton with, on the right, the shell dissected out.

Classification

The phylum is subdivided as follows:

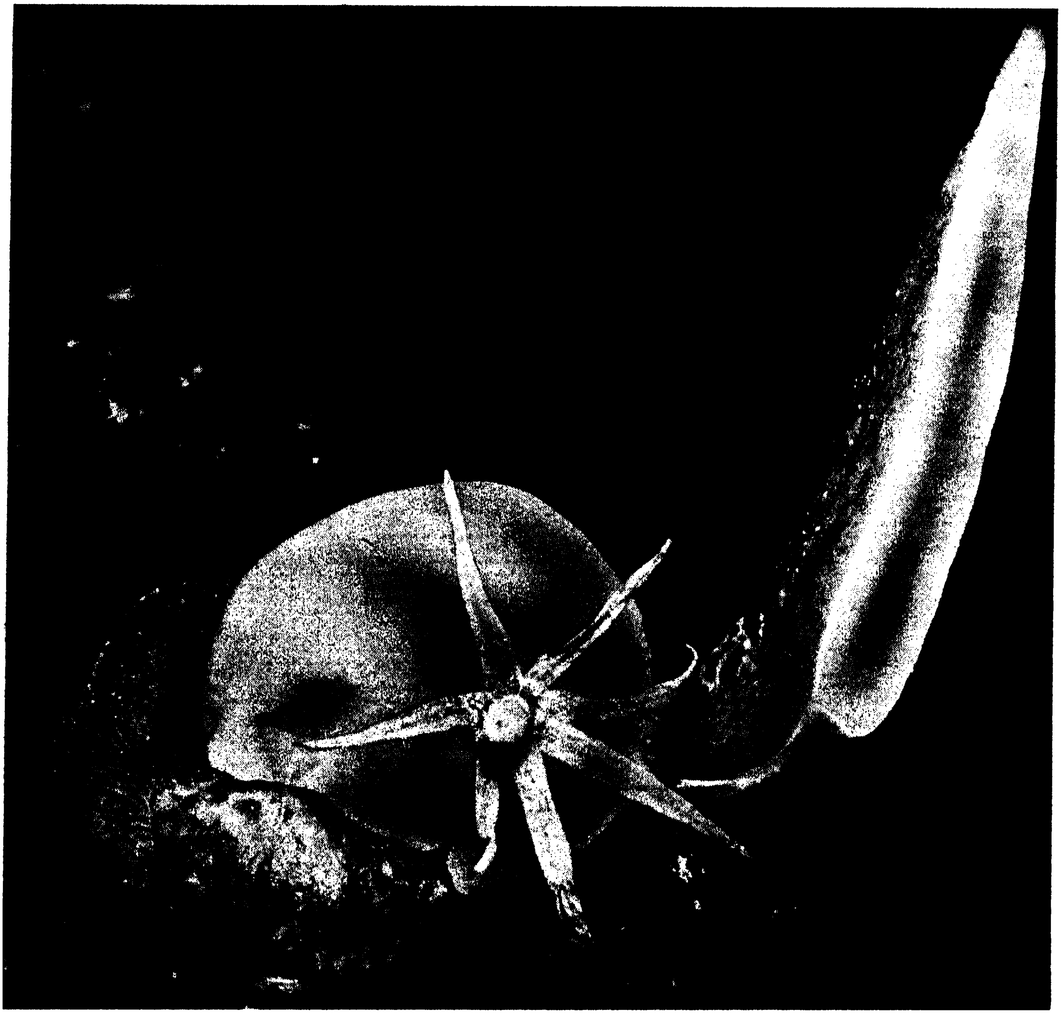
- Class Amphineura (the Chitons or Coat-of-Mail Shells);
- Class Gastropoda (Snails, Slugs, Whelks and their relatives);

Class Scaphopoda (the Tusk Shells);
Class Lamellibranchia (the Bivalves);
Class Cephalopoda (Squids, Octopus).

These classes are very unequal in size, the Amphineura and Scaphopoda being small and insignificant as compared with the enormous numbers of species in the Gastropoda and Lamellibranchia, and the striking appearance and size of the Cephalopoda.

Class Amphineura

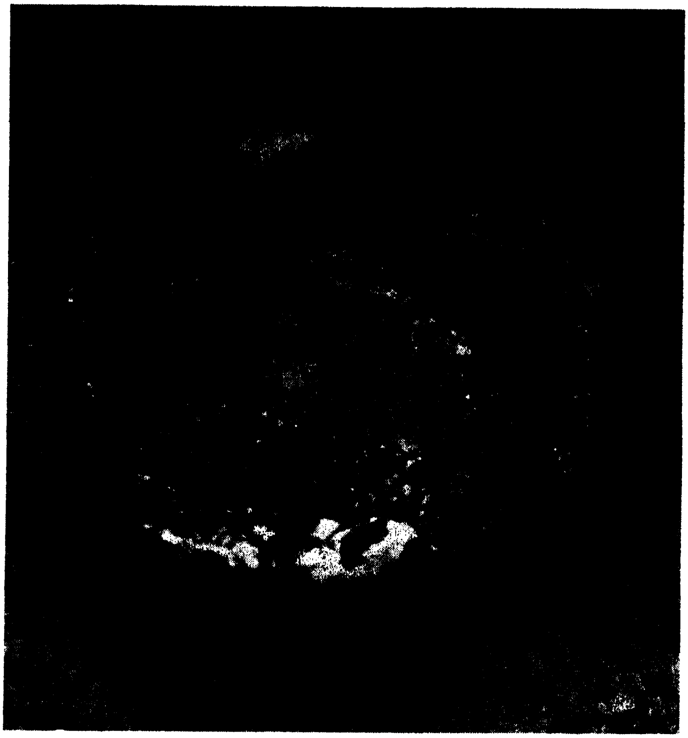
The members of this order are oval in outline, depressed, and with the dorsal surface protected by a row of 8 overlapping calcareous plates, representing the more typical shell of other Molluscs. The entire lower surface is occupied by a flat muscular foot, and the internal organs, enclosed in the mantle, are lodged within the cavity formed by the dorsal plates.



The American Black Slug feeding on a tomato. Slugs are hermaphrodite and the openings to the reproductive organs are located at the front end of the body, where we should normally expect to find an animal's ear.

Chitons live mainly in shallow water, between tide-marks and down to about 20 fathoms, although a few species occur at depths down to 2,000 fathoms. They range in length from half an inch to ten inches, as in the Giant Coat-of-Mail Shells (*Cryptochiton stelleri*) on the north-west coast of North America. During the day they are inactive, clinging by the foot to the surfaces of rocks; at night they creep sluggishly about to feed on small seaweeds. The dorsal plates are pierced by holes through which a number of minute eyes, the so-called "shell-eyes", project. Although a comparatively small and uniform class in most other respects, it is of interest to note that while most of the species lay eggs in the normal way, in a few the eggs are incubated in the mantle cavity, between the dorsal plates and the foot, and in at least one species, *Callistochiton magdalenensis*, the young develop inside the body of the parent.

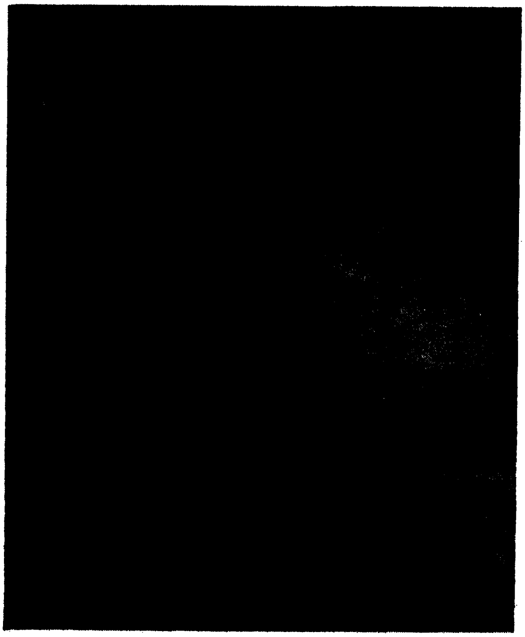
Two interesting cases of convergent evolution may be noted here. The normal Chiton, if detached forcibly from the rock, will slowly roll itself up for protection in much the same way as woodlice (among the Crustacea) and the armadillo (among the Mammals). The second concerns certain members of the Amphineura living in the mud on the sea-bed which have developed long cylindrical bodies and look exactly like worms.



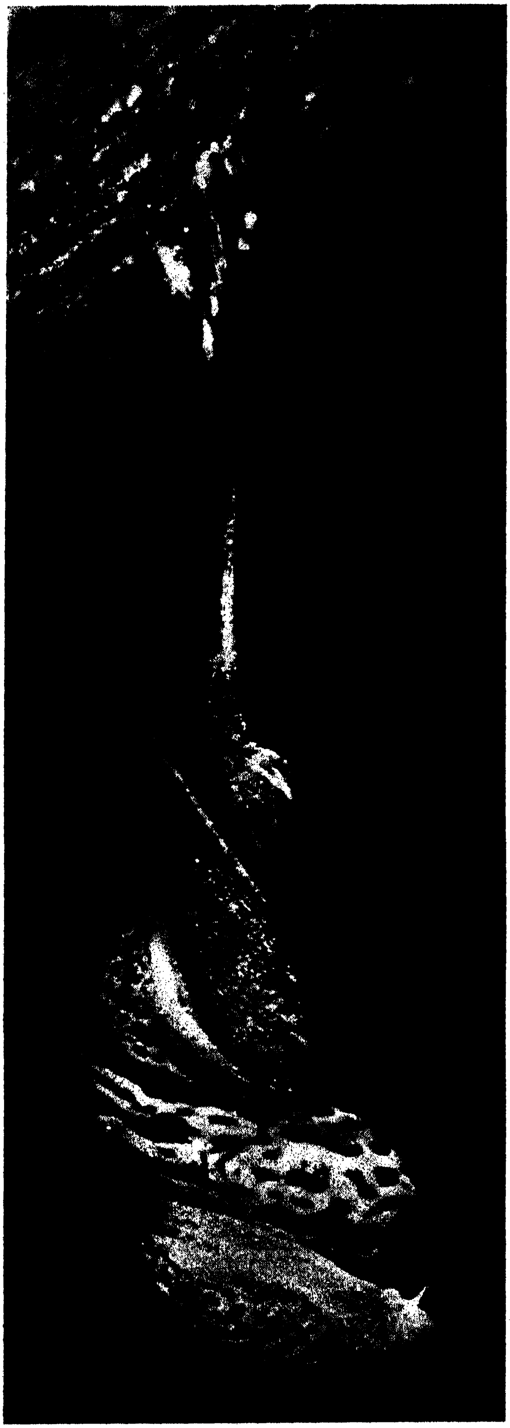
A pair of Black Slugs photographed at night by flashlight. They are on the bark of a branch of a tree preparing a base of slime, from which they will shortly descend.

Class Gastropoda

The members of this class, which contains nearly 40,000 species, are extremely versatile. Their common characteristic is exemplified in the name Gastropoda, or "belly-footed". In other words, they move about by means of the broad, muscular foot, and appear, as a consequence, to be walking on their bellies. This they share with the Chitons, but instead of having a row of plates for protection, they have a spirally-coiled shell, except where it has been secondarily lost, or where, as in limpets, it has been modified to some simpler shape. Even in these cases,



Snails pairing. Snails are hermaphrodite and, like earthworms, pairing means a mutual fertilisation.

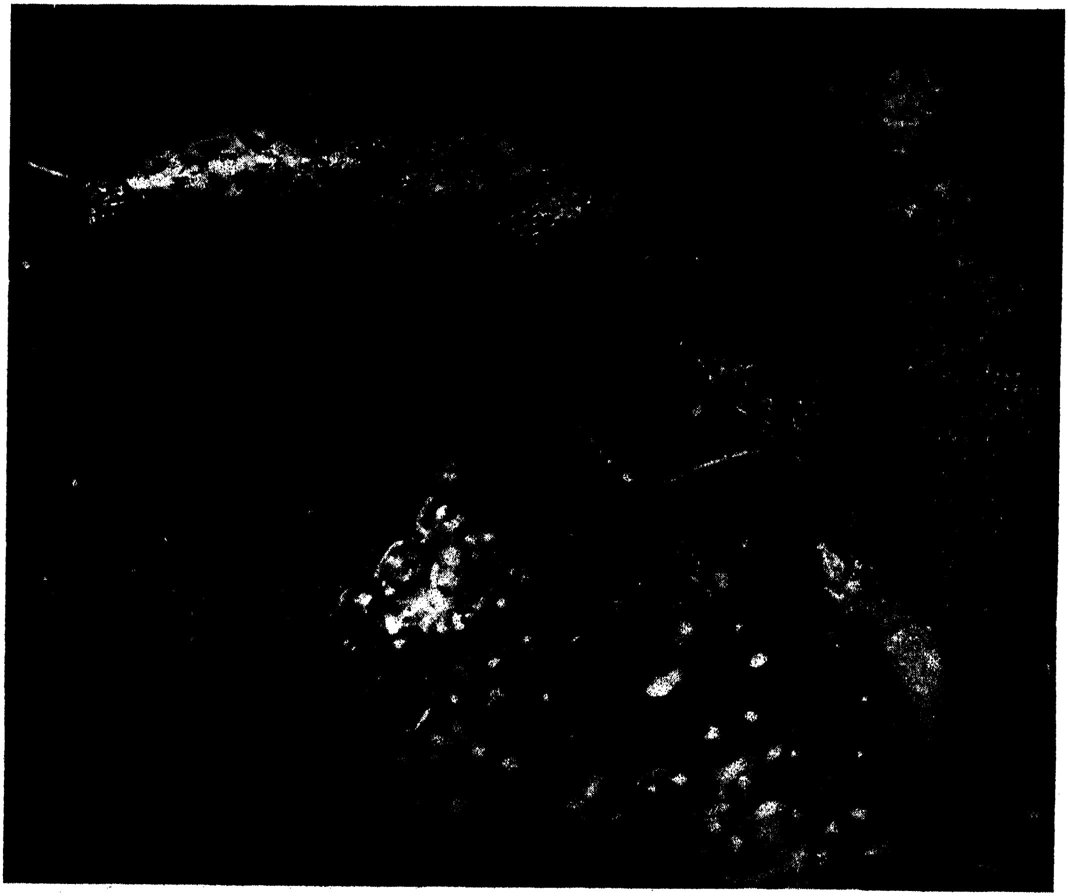


The next step in the pairing of the Black Slugs. From the base of slime, or mucus, they lower themselves on a chord of mucus, twisting their bodies round each other.

When pairing is complete, the slugs ascend the mucus chords, back to the branch, after which one of them cuts the mucus free so that it falls to the ground.

Brazilian Land Snails *(Borus oblongus)*. The fleshy foot with, in front, the ill-defined head are well-shown. (One-fifth natural size.)

however, the young possess a spiral shell, an interesting example of recapitulation in development. Snails, whelks and periwinkles have the familiar spiral shell; limpets, with the dome-shaped shell, and cowries, with the almost egg-shaped shells, are examples of a modification



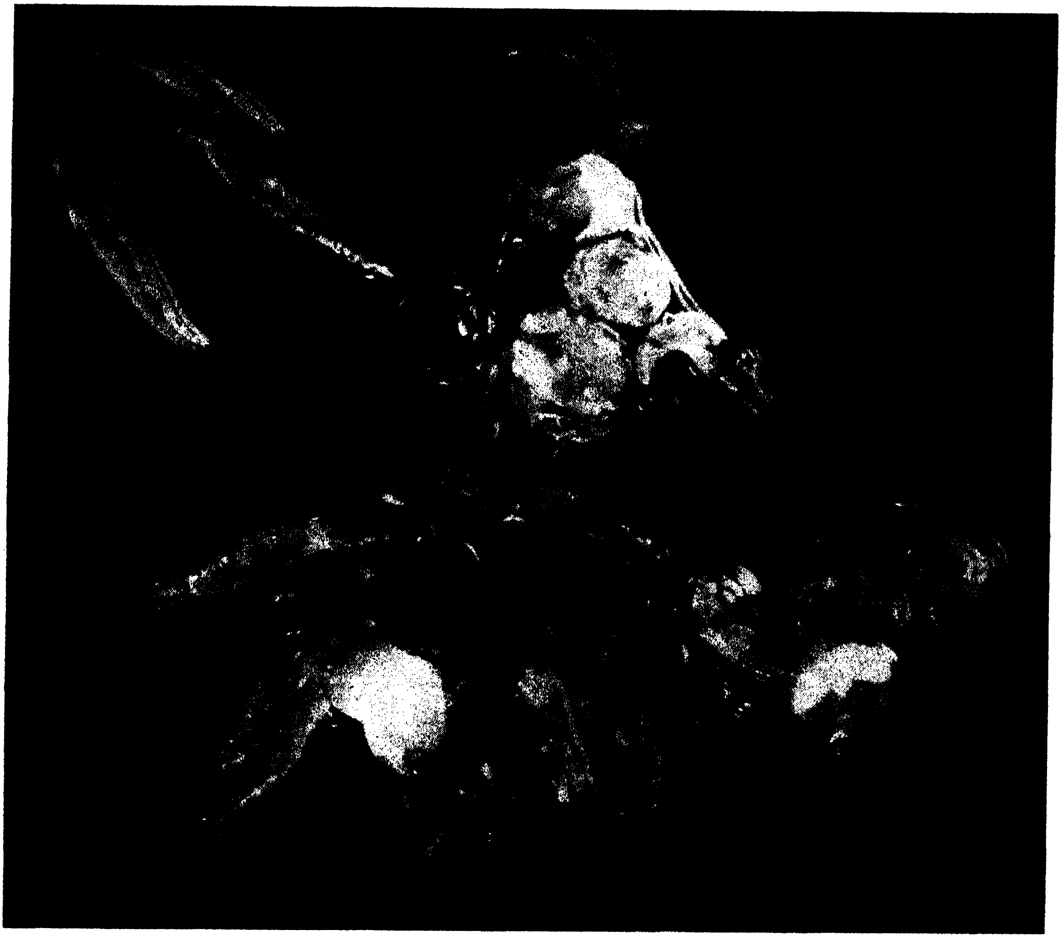
A Black Slug with a batch of newly-laid eggs.

from the spiral; and the land slugs and sea-slugs have the shell either reduced to a vestige and enclosed within the body or it has disappeared entirely.

The Gastropods inhabit the seas, the land and the freshwaters. For the most part they are vegetarian, living on any form of plant life, even on decaying vegetation, but a few of them are carnivorous. In the seas they are most abundant between tide-marks, and in the shallow off-shore waters, where sea-weeds are abundant, but many others live on the bottom of the sea at greater depths feeding on the debris of sea-weeds washed down by the currents. Some of the marine forms are, however, found in the great abysses of the oceans, and these must of necessity be carnivorous.

On land they are found in fields, woods, gardens and hedgerows, among the lichens and mosses growing on rocks, in the tropical forests, in the deserts, on the edges of glaciers and on sand-dunes. Others are found in rivers, streams and ponds, in brackish water, mangrove swamps, in torrents and even in hot springs. A few have become parasitic, such as *Magilus* which burrows into coral and *Stylifer* living in starfish.

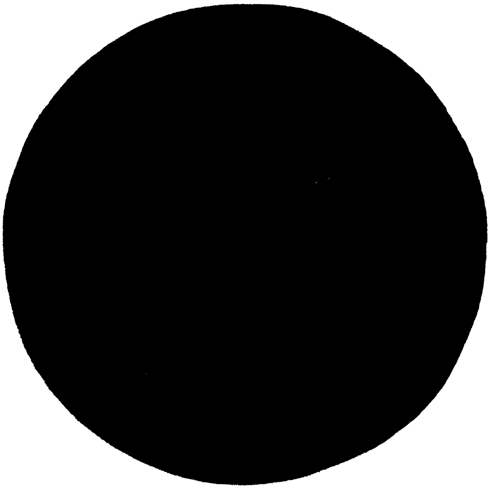
The shell offers protection not only from enemies but from drought and intense heat and, in marine species, against the battering action of the waves. To make it more effective the



Young slugs hatching from the eggs. Some can be seen in the act of leaving the egg. The young are an eighth of an inch long, the parents six inches.

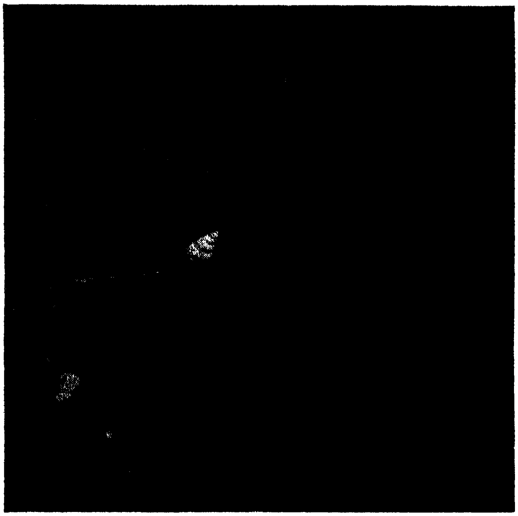
animal, after it has withdrawn into it, can seal the shell by means of a hard plate, or operculum, carried on the back of the foot, or by a temporary shield, or epiphragm, secreted by the foot.

In all marine Molluscs, whether it be the chiton. whelk or periwinkle, bivalves such as mussels, oysters or clams, or the ferocious squid or octopus, respiration is carried out by gills lodged in the mantle cavity. In land snails and slugs, however, the gills have been lost and, as befits a terrestrial animal drawing oxygen from the air instead of from water, the mantle cavity has been converted into a lung. Moreover, the freshwater snails also have a lung cavity and can breathe air, showing that from a terrestrial ancestry they have reverted to an aquatic life. But they can also take in oxygen from the water by means of secondary respiratory organs developed from folds of the mantle. In practice, therefore, water snails have both a lung and gills.

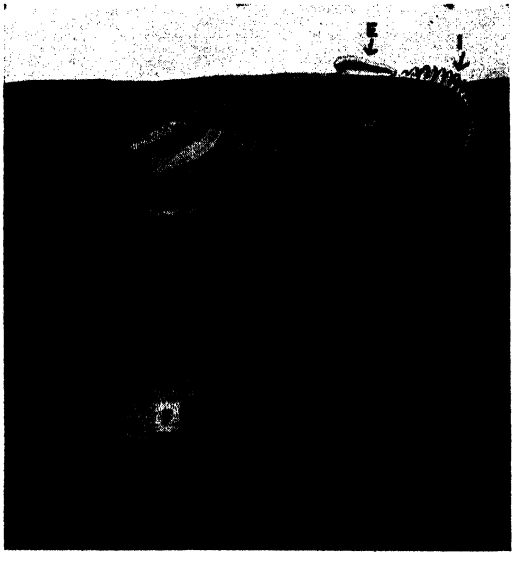


The tongue or radula of a snail (*Helix aspersa*), showing the rows of very numerous small teeth. (Magnified 60 times.)

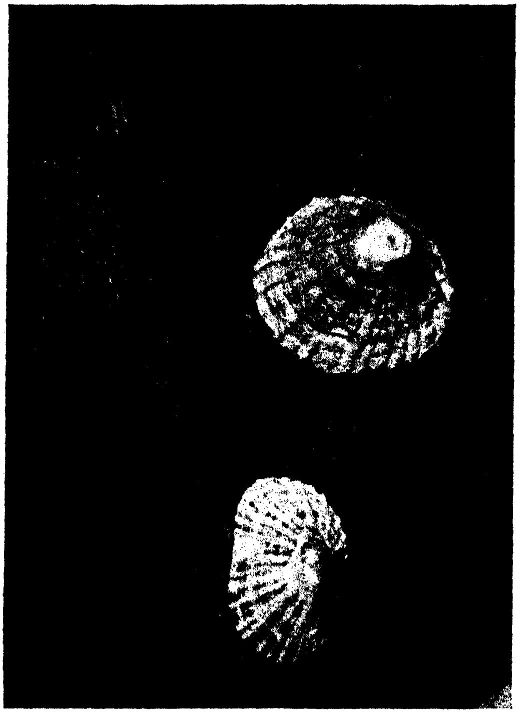
The first type of Gastropod to be dealt with are the limpets, which are found in nearly all parts of the world, more especially on the shore between tide-marks, although some specialized forms are found at depths of over 2,000 fathoms. They live on rocky shores, adhering to the surfaces of the rocks by means of a sucker-like foot which has an adhesive power so strong that a force of 62 pounds, or nearly two thousand times its own weight, is required to dislodge it. This is obviously a protection both against the action of waves and against sea-birds and other enemies. The foot secretes an acid which excavates the surface of the rock leaving a shallow depression having the exact outline of the limpet. The Common Limpet of Europe (*Patella vulgata*) has a well-developed homing



A mollusc, *Stylifer* sp., parasitic on the starfish, *Craspidaster hesperis*. The mollusc has a special foot for holding on to the starfish, on which it feeds. (Natural size.)



A Swan Mussel (*Anodonta cygnaea*) embedded in mud. A diagrammatical section showing the muscular foot (F) and the inhalant (I) and exhalant siphons (E).



Limpets, like snails, have a strong homing instinct and always come back to the same spot to rest. (Natural size.)

instinct and will return to its 'hole' regularly and fit itself accurately into the depression after its forays in search of the seaweeds on which it feeds.

The True Limpets vary in size from a quarter of an inch across, as in *Lepeta*, to nearly a foot across, as in the large *Ancistromesus mexicanus*, one of the Key-hole Limpets, of western Central America.

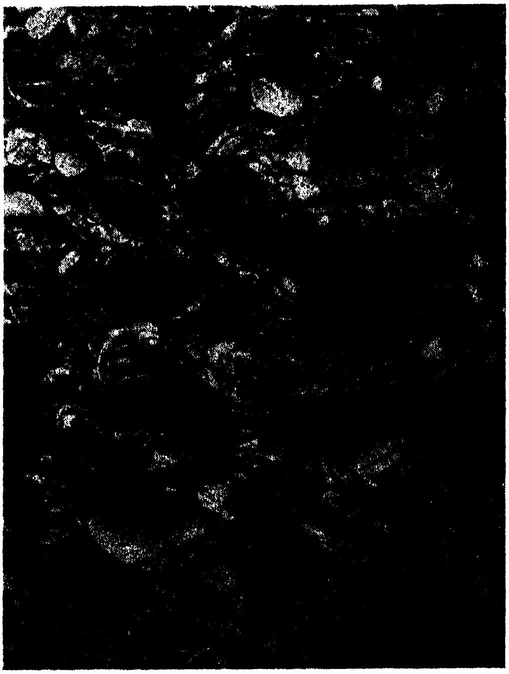
Closely-related to the True Limpets are the Ormers or Ear-shells, the Key-hole Limpets and the Top Shells. The Ear-shells, famous for their beauty, may be best described as large snail shells in which the spiral form has been so flattened as to be almost wiped out and in which the opening has been enormously enlarged. Along one margin is a series of round holes leading into the breathing chamber. *Haliotis cracherodii*, the Abalone of the Pacific coast of North America, is caught for food and its shell is used in making pearl buttons and buckles, and for inlaying. The smaller *Haliotis tuberculata* of Europe is also eaten in some countries.

Key-hole Limpets have a shell shaped like that of the True Limpet, but there is an oval hole at the top, and the shell in the living animal is covered by folds of the mantle.

The Top Shells have conical shells, showing the typical spiral, which are singularly beautiful. They are common between tide-marks.

So far, we have dealt with marine Gastropods only, all breathing by gills situated in the mantle cavity. The related Apple snails of America, living in freshwater, with large round green shells, have both a lung and a gill, and are amphibious. When in the water they can shut off the lung from contact with the water, when on land they can shut up the gill chambers and breathe by the lung. Some species have gone one step further and have a long tube, or siphon, by which air can be drawn into the lung when actually under water.

The condition found in the Apple snails is foreshadowed, however, by the Periwinkles, which include some forms that are practically amphibious. The common *Littorina littorea*, of



Shells and shell-fragments enter into the composition of the shore and the sea bed on the continental slope. In some places are found "shell-beaches" where the beach is composed entirely of shells.

The American Slipper Limpet *(Crepidula fornicata)*, accidentally imported with American oysters, has spread rapidly round the south and east coasts of England. It is normal to find several individuals in a pile one on top of the other. Each individual undergoes a change of sex in its lifetime. (One-third natural size.)

the coasts of Europe and the British Isles, has a mantle cavity showing signs of becoming a lung, and although it lives normally between tide-marks, may sometimes be found on land some distance from the sea, living at least partially the life of a land animal.

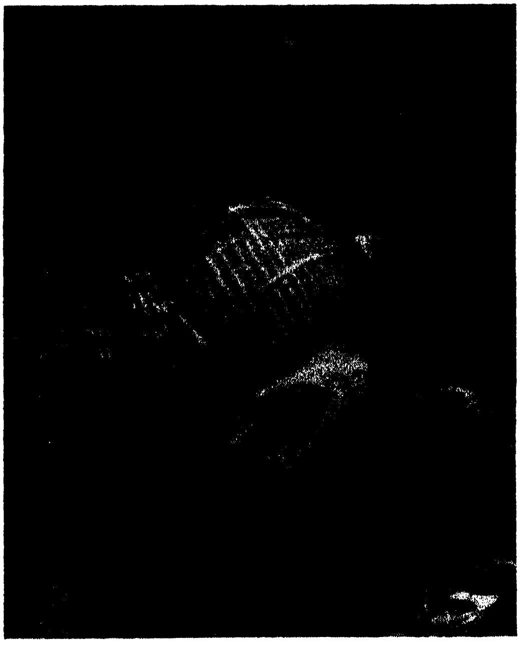
The Slipper limpet, *Crepidula fornicata*, is of especial interest. Its shell has almost lost the spiral formation, so that it bears a superficial resemblance to the shell of the true limpets. It was accidentally imported into British waters with American oysters some years ago and has spread rapidly along the south and east coasts of England. Some idea of the way in which this pest of oyster beds has become established and has multiplied may be gauged from the fact that it is removed from the beds by the ton each year without any appreciable check to its growth.

The class includes also the Worm-shells, Cowries and the free-swimming Heteropods. In the first of these the shells remaining uncoiled have a resemblance to the calcareous tubes of some of the marine worms, which is heightened by the fact that the animals live in masses with their shells fixed to the surface of a rock or a coral. The Cowries have shells which appear at first sight to have lost their spiral character entirely, being nearly globular but with one side flattened and with the aperture transformed into a long slit. Internally, however, the spiral plan can be seen, the last whorl having enclosed the rest.

In the Heteropoda the foot is flattened from side to side and is used as a swimming organ. The shell is much reduced and the whole body nearly transparent. Heteropods are carnivorous and swim in large numbers at or near the surface of the sea. As an adaptation to the pelagic mode of life their eggs are embedded in a buoyant mass of jelly, so that they float at the surface.

Suborder Stenoglossa (Whelks)

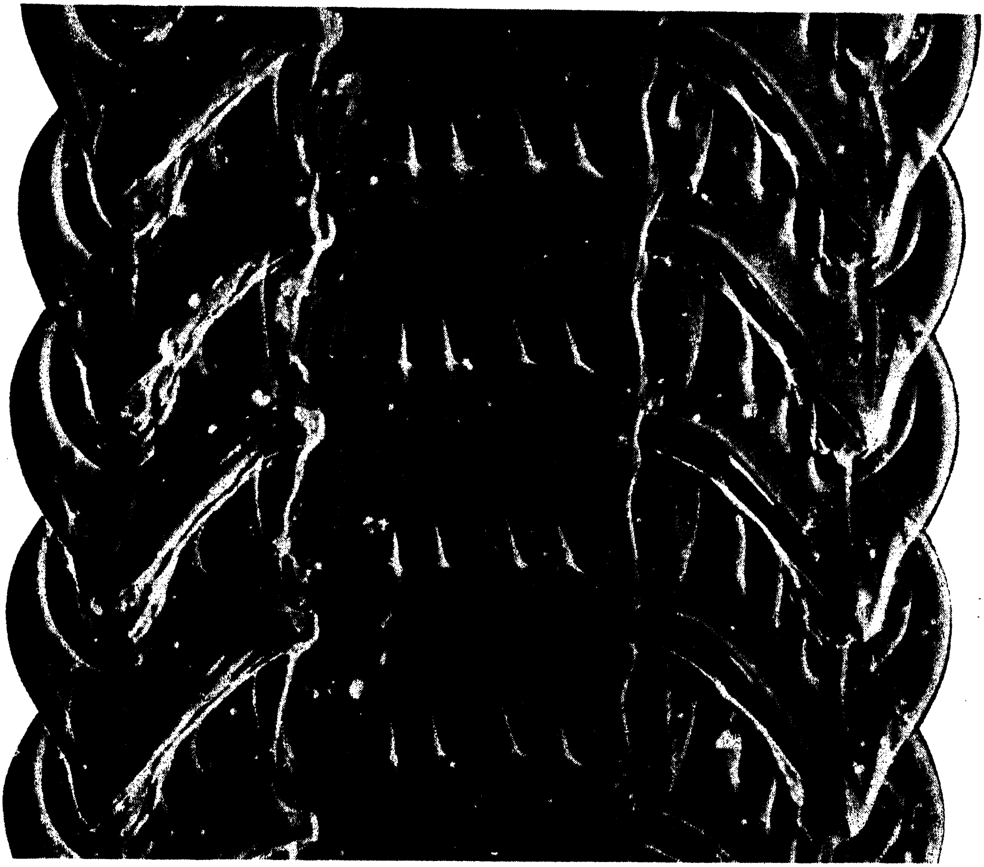
Although the radula is narrow and is armed with only three rows of teeth, the members of this sub-order are all carnivorous. Some, like *Fasciolaria gigantea*, on the coast of South Carolina, and *Megalotractus aruanus* of Australia are nearly two feet across. Most of them live by boring through the shells of other mollusca and extracting the soft bodies contained therein. The Cone Shells, on the other hand, which include some of the most beautiful shells known, use the teeth of the radula as poisoned barbs



A Whelk with its foot extended, showing the siphon and the antennae. On the rear end of the foot is the operculum which blocks the entrance to the shell when the whelk has withdrawn into it.

with which to kill their prey. In them, the radula is no more than a store of barbs, to be used one at a time, but the mechanism by which this is effected is not clearly known.

The Subclass Euthyneura of the Gastropoda includes the Land Snails and Slugs, the Freshwater Snails and the Sea Slugs. This contains two orders: the Opisthobranchia and the Pulmonata.



The tongue or radula of a whelk (magnified 130 times).

Order Opisthobranchia

The majority of the members of this order have little resemblance to the hard-shelled forms so far considered. The Sea Hares, for example, have the margins of the foot extended to form swimming lobes, and the shape of the body with its large tentacles give a fanciful impression of a crouching hare, with ears erect. The Pteropods are small and pelagic, so numerous in the sea that some 500,000 square miles of the sea-bottom are covered with a thick accumulation of their shells which, after the death of their owners, have sunk down to about 1500 fathoms to form what is known as the Pteropod Ooze. Some of them have the foot drawn out on either side into wing-like lobes, and their appearance has earned them the name of Sea Butterflies.

The remainder of this order are known as Nudibranchs or Sea Slugs. A typical Sea Slug has a body closely resembling that of the Land Slug, but more beautifully coloured. Indeed, the colouring in some Sea Slugs is exquisitely delicate and unsurpassed by that of any other marine animal. Often the back is ornamented with long finger-like papillae. Although some are pelagic, the typical members creep about the sea bottom devouring sponges, hydroids and other sessile animals. Those that feed on hydroids make use of the nematocysts in a singular way. These are indigestible and pass up into the dorsal appendages of the Nudibranchs, where they are stored up in special chambers and are shot out at their enemies when attacked.

Order Pulmonata

This is the largest order of Mollusca, and one of the most flourishing groups in the Animal Kingdom. Its members are mainly terrestrial, but some families live in fresh water, and a few are marine. Respiration is by means of a lung formed from the mantle cavity, but, unlike the lung of the limpets, the edges of the mantle cavity become fused so that only a small contractile opening is left. The order is divided into two sub-orders: the Basommatophora, or Freshwater Snails, and the Stylommatophora, the Land Snails and Slugs.

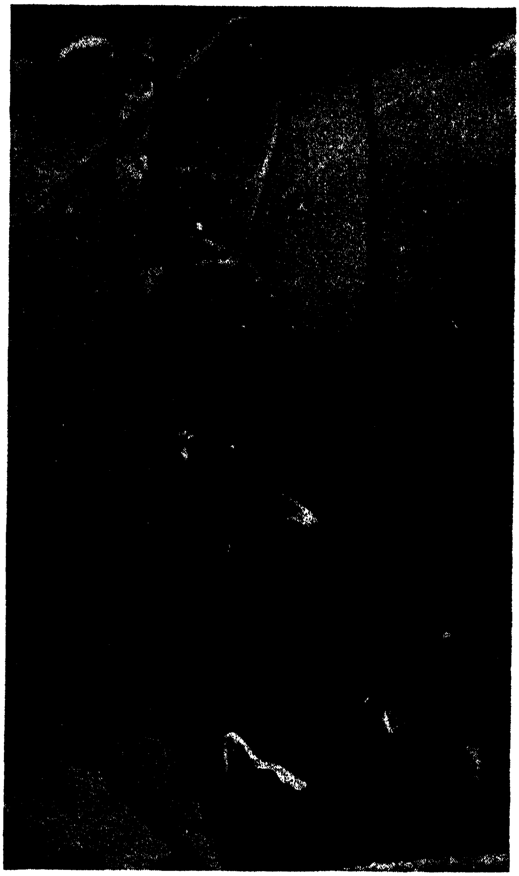
Sub-order Basommatophora

The Freshwater Snails are terrestrial snails that have become readjusted to a life in water. They are very abundant all over the world, and can be readily found in any pond, stream or river, creeping along on the underside of the surface film, or feeding on living or dead plants. The Tadpole Snails (*Physa*) secrete threads of mucus, extending from the bottom of the pond to the surface, up or down which they can move rapidly.

The members of this sub-order are very adaptable. Not only are they found in freshwater but also in brackish waters and in sulphur springs. One species, *Limnaea hookeri*, lives at 17,000 feet in the Himalayas. Others are found at great depths in the very deep lakes.

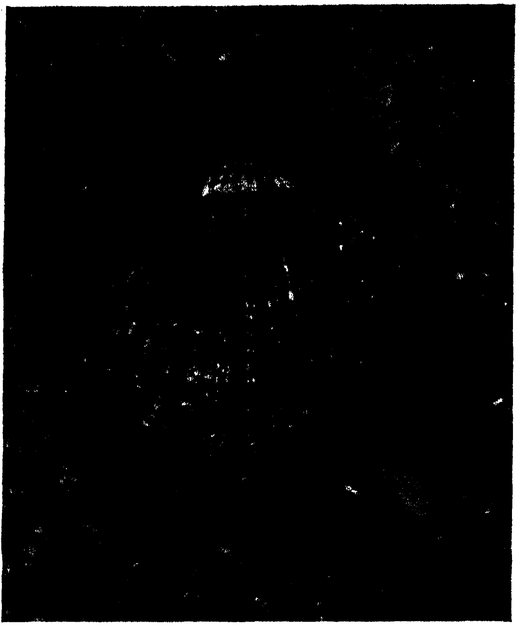
Sub-order Stylommatophora

The members of this sub-order are all terrestrial except for one family of Marine Slugs, which look very like the Nudibranchs. They differ from the Basommatophora in having two pairs of tentacles instead of one, with a pair of eyes on the tips of the hinder pair. Most of them are vegetarian, but a few are carnivorous, such as the species of *Glandina* which feed on other snails, or the species of the Testacellidae which feed on earthworms and other small invertebrates. Although the majority have the usual snail shell, more or less modified, in the Land Slugs this is variously reduced, either to a small, degenerate shell at the hind end of the body, as in *Testacella*, or to an irregular calcified mass as in *Arion ater*, or even a few calcareous granules embedded in the skin.



The Pond Snail (*Limnaea stagnalis*). (Two water spiders can also be seen in the picture). (Natural size.)

The typical terrestrial snail or slug moves about by laying a pavement of mucus, by means of which it can travel over rough or smooth surfaces. A slime gland at the front end of the foot secretes the mucus.



The cockle (*Cardum edule*) with the foot extended.

Order Scaphopoda (Tusk or Tooth Shells)

In this is included a small group of aberrant forms sufficiently unlike the typical mollusc to be included formerly among the worms. The body is elongated and is enclosed in a curved tubular shell, open at each end, smaller at one end than the other. The empty shells often flung on the beach recall miniature tusks. The animal lives half buried in the sand, feeding on microscopic plants and animals, and breathing through the opening in the narrow end of the shell, the tip of which is all that is left exposed above the sand.

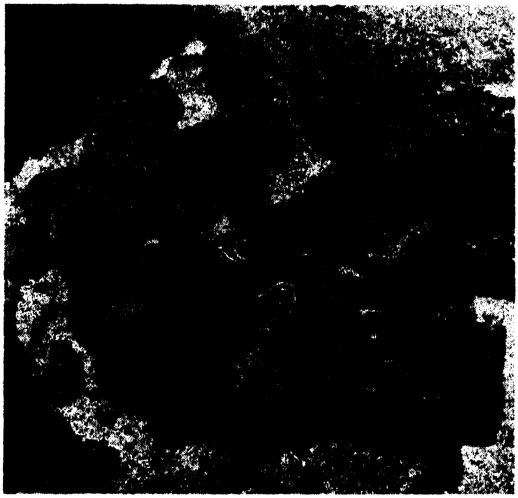
Class Lamellibranchia

The bivalves or Lamellibranchia, which include the oysters, mussels, cockles, scallops and clams, is the largest class of molluscs after the Gastropoda. Instead of the one, spirally-coiled shell of the latter theirs consists of two parts, or valves, hinged on each other. Although so different in outward appearance, the anatomy is essentially the same as that of other molluscs, with the muscular foot and the mantle cavity, containing gills, for all bivalves are aquatic, living either in the sea or in fresh water.

Lamellibranchs are for the most part sedentary, passing their lives fixed to the rock by one valve, as in the oyster, or anchored to the rock by a bunch of glutinous hairs, the byssus, as in mussels; but the great majority burrow in the sand, and in order to breathe while tunnelling are provided with siphons to maintain connection with the water. A few are capable of vigorous movement, such as the cockle, which is capable of leaping several feet into the air when making its way to the water's edge at low tide; or swimming, like the scallop, vigorously expelling water by the opening and shutting of its valves.

All bivalves feed on microscopic organisms and, consequently, have no radula.

The edible mussel furnishes the most striking example of the immense numbers of bivalves living in the sea. At low tide they may be seen in countless millions on the mud flats, on pebbly or rocky shores. Nevertheless, other bivalves must run them close in this respect, but because they are of burrowing habit they are not so readily seen. In many places the sandy beaches



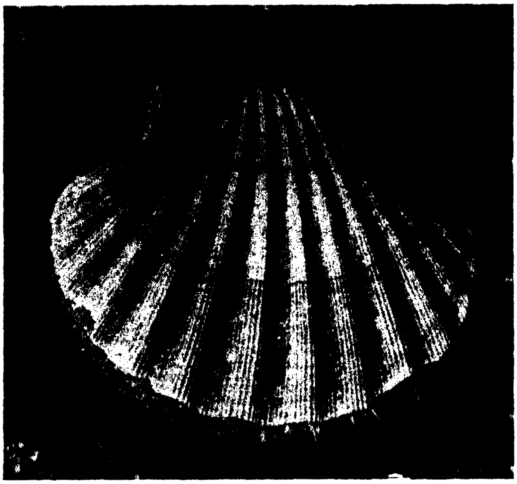
The Giant Clam *(Tridacne)* showing the edge of the mantle exposed to illuminate the microscopic algae growing in the tissues. The clam also feeds by filtering the sea-water, and here the siphon is seen by which water is taken in. The Giant Clam may reach a length of 4 feet and the edge of the mantle is brightly coloured, in this case emerald green with yellow gold flecks.

are, however, formed very largely of the broken fragments of their shells.

Before leaving the Lamellibranchs, mention must be made of the most unusual among them, the Shipworms which honeycomb the piles of wharves and piers and other submerged timbers doing considerable damage. *Teredo navalis*, some six inches long, has a cylindrical body, with the valves very much reduced in size and situated at one end of the body. The animal secretes a calcareous lining to its burrows (see p. 175).

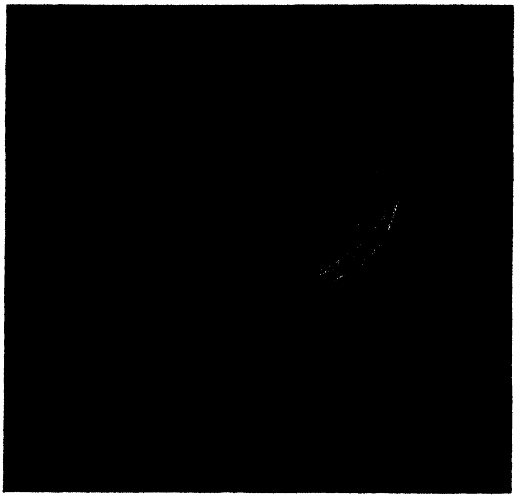
Class Cephalopoda

It is difficult to believe that the active squid and octopus are so closely related to the sedentary oyster and clam, yet the anatomy of all four, as indeed of all molluscs, is remarkably similar. The foot, so conspicuous an organ of locomotion in the Gastropoda is, in the Cephalopoda, merged with the head, and from the mass so formed extend the long arms beset with suckers which constitute the formidable weapons of offence. The shell, except in the Pearly and Paper Nautilus, is much reduced and enclosed within the body, forming the well-known cuttlebone, or in other cases forming a fragile horny 'pen' (see p. 211).



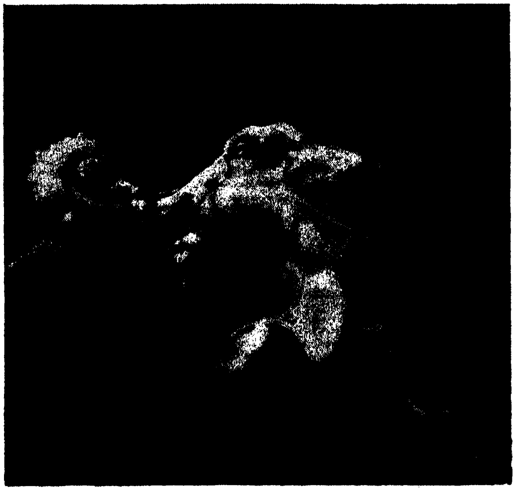
A scallop *(Pecten)* showing the fringe of tentacles around the edges of the mantle with which the two valves of the shell are lined. (One half natural size.)

Beneath the head a siphon protudes from the mantle cavity. Through this, water is expelled with such force as to drive the animal swiftly backwards. When attacked, a cloud of ink can be ejected from an ink sac contained within the body, under cover of which the animal makes its escape.

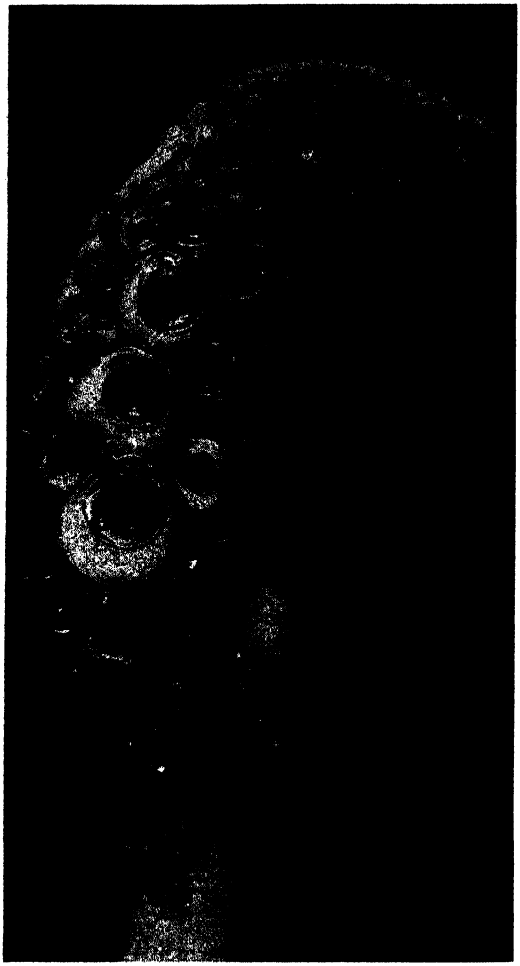


A marine lamellibranch (*Mya*) with the two respiratory siphons extended.

One of the most remarkable features of the Cephalopoda is the conspicuous pair of eyes, closely resembling the highly organised Vertebrate eye, but without lids. Coupled with this, and doubtless working in conjunction with the



The common Octopus *(Octopus vulgaris)* seated on a rock.



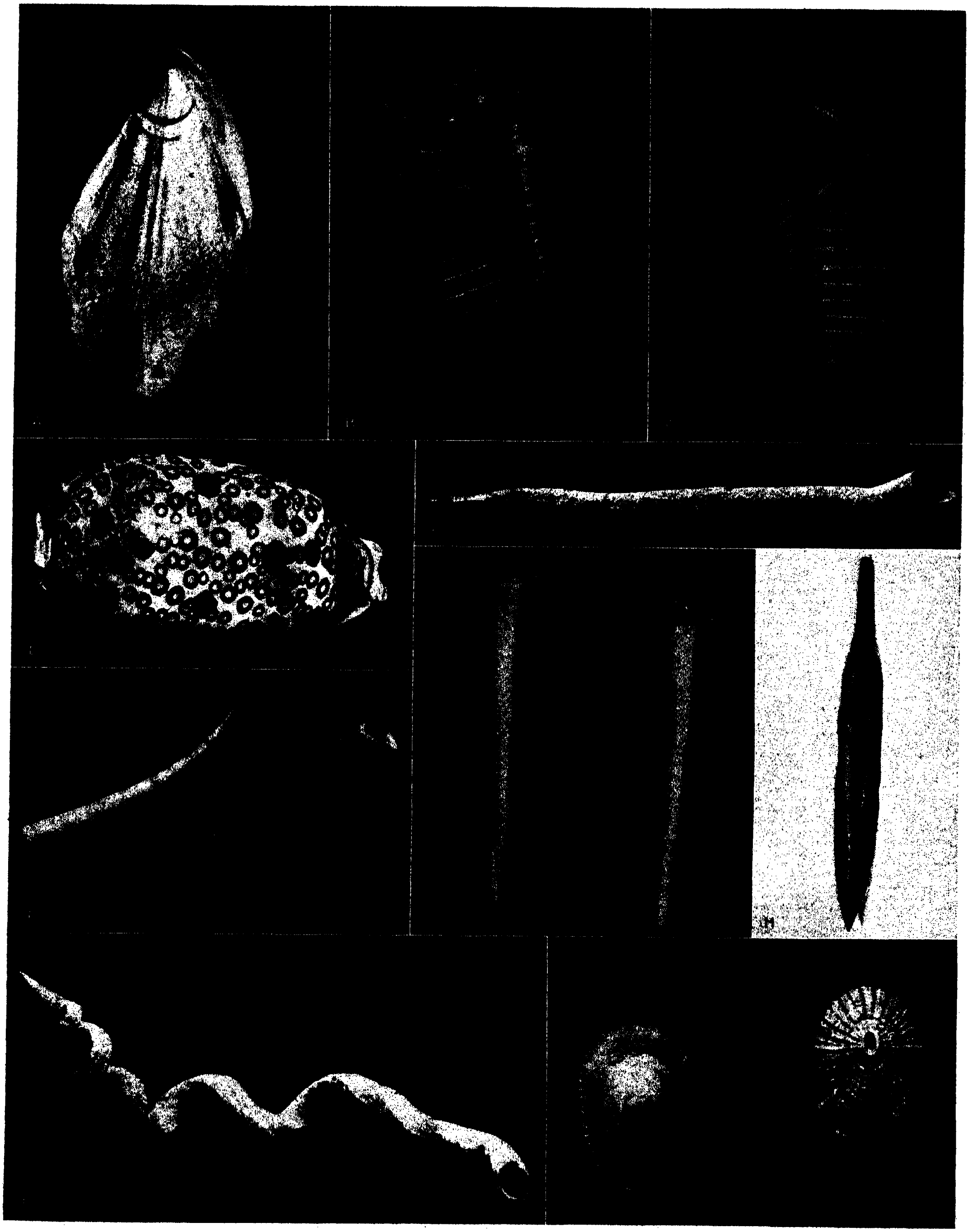
The tip of one of the long tentacles of the Cuttlefish *(Sepia officinalis)*. (Slightly enlarged.)

powerful vision, is an unusual ability to change colour rapidly. In the skin are lodged a number of chromatophores which by rapid expansion or contraction bring about instantaneous changes from almost white to black, and other combinations of colours, such as blue, purple, red or yellow. Through these changes the animals have the ability to harmonize rapidly with the colour of the background.

Squid, which have ten arms, live mainly on various kinds of crustacea, move about in shoals, often in such numbers that the sea is literally alive with them. In 1900 a plague of them invaded the English Channel, causing such havoc that the crab-fishery on both the English and French coasts was wiped out. In the deep seas, squid of enormous size form the food of the large toothed whales. The largest known, *Architeuthis princeps*, of the North Atlantic, measures 55 feet total length, including the tentacles; but there is reason to believe that squid, as yet uncaught, may measure up to 100 feet. In some parts of the world their flesh is used for human consumption; in other places it is used for bait, as in the Newfoundland cod-fishery.

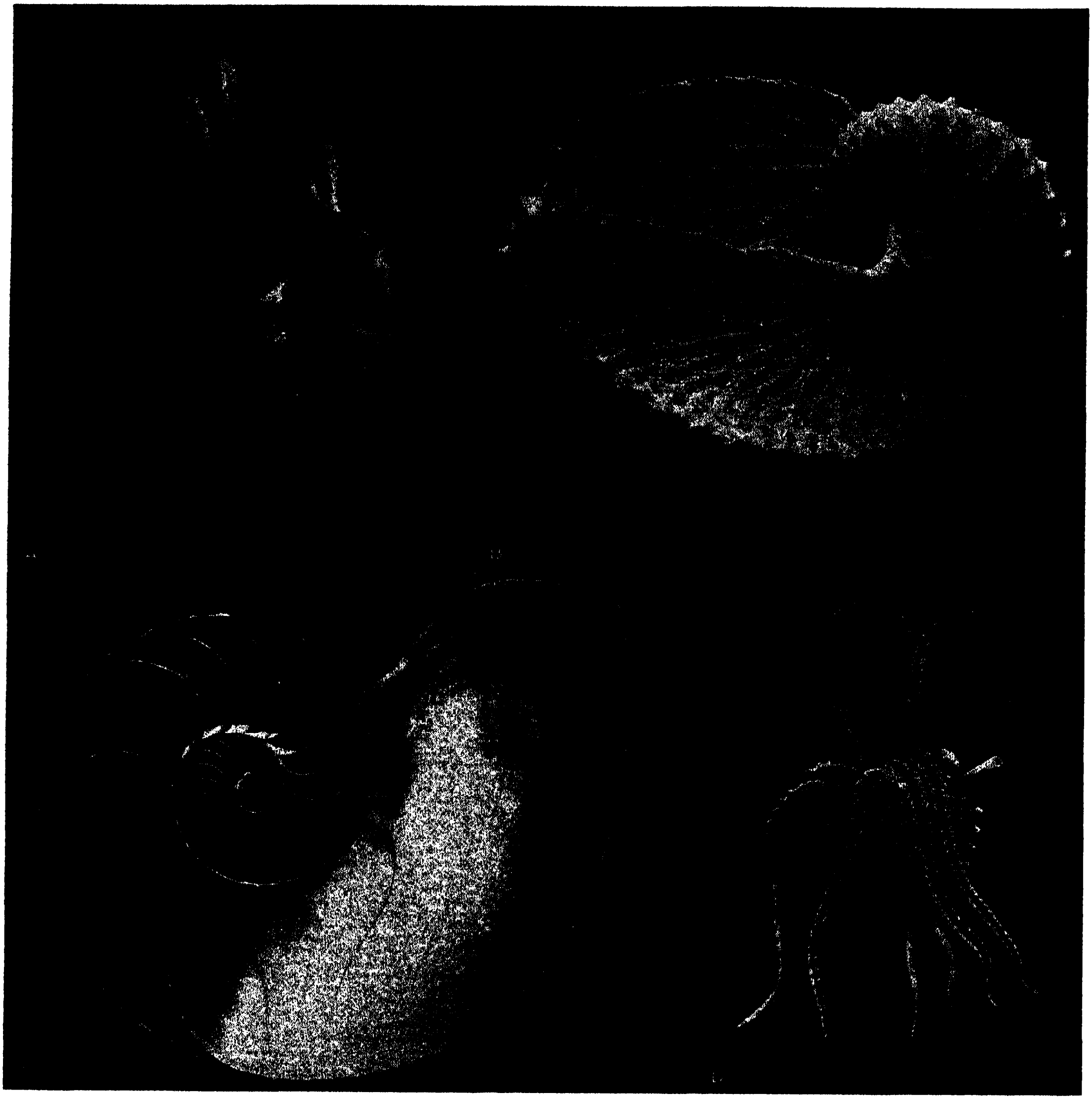
Octopus, with eight arms, also feed on crabs which they, like the squid, tear to pieces with their powerful parrot-like beaks. Unlike the

Cuttlefish eggs, looking like a bunch of black grapes, with a young cuttle newly hatched and a second just leaving the egg. (Slightly more than natural size.)



Forms of Shells.

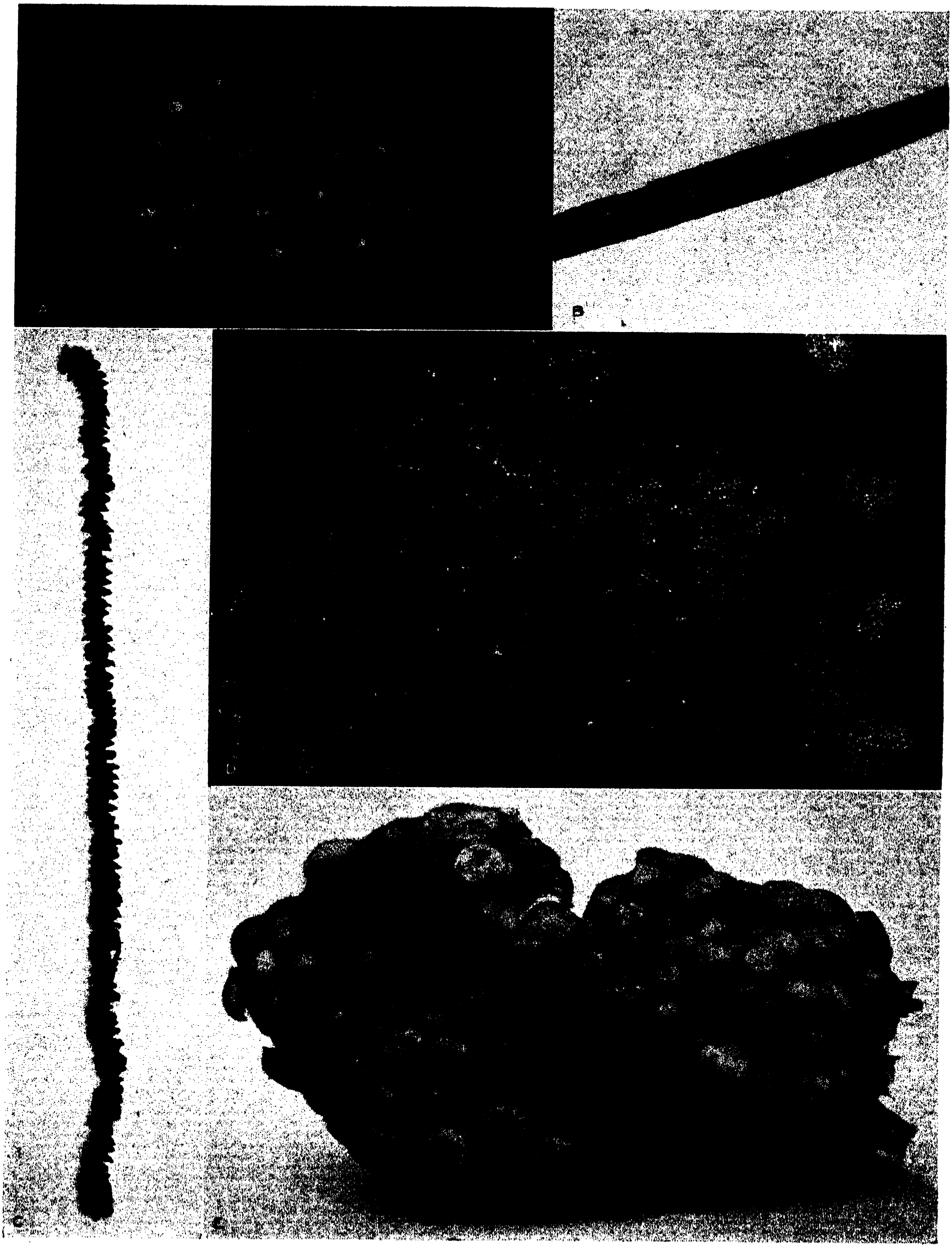
A. The internal shell of a Cuttlefish, the so-called cuttle-bone. B and C. *Murex tenuispina*, from the Indian Ocean. D. A cowrie, *Cypraea argus*. E. *Kuphus arcuarius*, part of the shelly lining of the burrow of a mollusc, allied to *Teredo* (see p. 175), which lives in the mud of mangrove swamps. F. The Elephant Tusk Shell, *Dentalium entalis*. G. Watering Pot Shells, *Aspergillum* sp. H. The horny internal 'pen' (i.e. all that remains of the shell) of the squid. I. One of the Worm Shells, *Venetus spiralus*. After starting to construct a normal shell, this mollusc finishes off with a long open spiral. J. The Keyhole Limpet (*Fissurella graeca*) showing, on the left, the inside of the shell, and, on the right, the shell from above.



Forms of Shells.
A. The shell of the Pearly Nautilus. B. The Paper Nautilus (*Argonauta tuberculosa*) from S. Australian waters. C. Section of a Nautilus shell, showing the separate chambers. D. Diagram showing the Argonaut seated in its shell. It was formerly believed that the flattened tentacles were held aloft to act as sails while the animal floated in its shell at the surface of the sea (as shown in this drawing). This story is now discredited.

squid, however, octopus tend to lurk in submarine caves, in crevices in rocks, among coral or on the sea bottom.

The Pearly Nautilus has a coiled shell divided by crosswalls into a series of compartments. As the animal outgrows one compartment it secretes a new chamber, sealing it off from the one behind it by a wall. The empty chambers are filled with a gas, making the whole buoyant, so that although having to transport such a heavy shell the Nautilus is still able to hunt crabs actively. To-day, Nautilus is found around certain South Pacific Islands only, at about 100 fathoms; but its ancestors, which include the well-known Ammonites, were extremely numerous and widespread in earlier periods of the Earth's history.



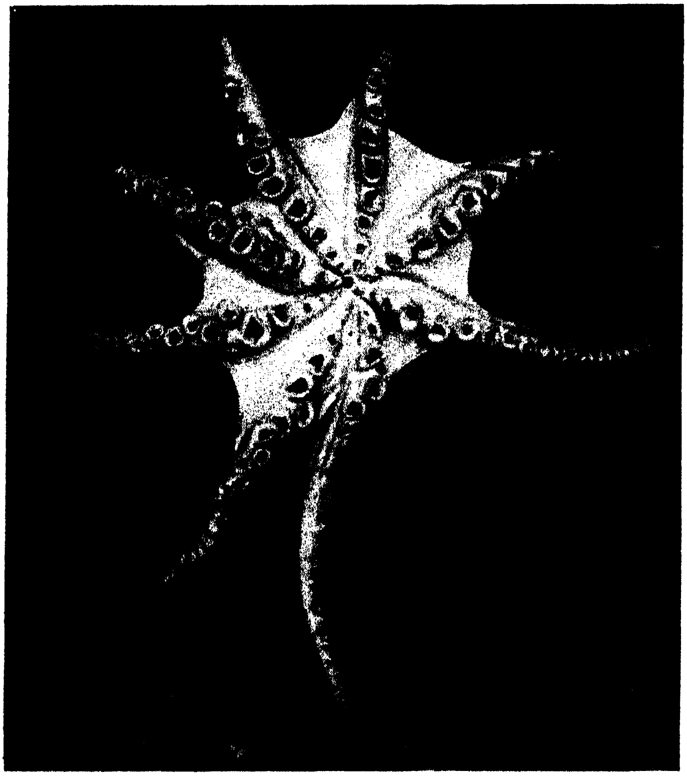
Some Mollusc eggs.

A. Eggs of the Garden Snail *(Helix aspersa)*, magnified 1½ times. B. A split, decayed grass stem chosen by a small slug as a receptacle for its eggs, magnified 3 times. C. Egg chain of the Turret-shell Snail, about natural size. D. Eggs of an oyster, magnified 8 times. E. Egg clusters of the Whelk, *Buccinum*, slightly enlarged. Each capsule contains an egg.

GIANT OCTOPUS AND SQUID

Since early historic times there have been stories of giant octopus and squid, and such stories are still current. It may be they have a foundation in truth, for we do not know all there is to be known about life in the seas, particularly in the depths of the oceans. The largest measurements recorded are, however, much less than those hinted at in such stories. The largest octopus, for example, *Paroctopus apollyon*, from the west coast of North America, has a radial spread of the arms of 28 feet, while the body is no more than a foot long and six inches in diameter. The largest squid has larger dimensions than this. It is *Architeuthis princeps* which measures 55 feet from the hinder tip of the body to the tip of the two outstretched long tentacles. In the opinion of those best qualified to know, it is possible that giant squid may measure 60 feet or more, possibly 100 feet long, judging from the size of the marks made by their suckers on the bodies of sperm whales, which feed on them. But there is no evidence for the 180 or 200 feet sometimes suggested.

On the other hand, cephalopods, and more particularly squid, abound in large numbers, particularly in the deep waters of the Antarctic. Even in other parts of the world, where specimens of *Architeuthis*, four feet long, are sometimes stranded on the shore, squid not infrequently occur in numbers sufficient to constitute a plague. There was, for example, the plague of squid in the English Channel in 1900 which completely ruined the lobster and crab fisheries on both the English and the French coasts. Until they departed, even the large crabs sought refuge in shallow waters and could be picked up on the shore when the tide went out.



An Octopus showing the mouth at the centre from which the sucker-laden tentacles radiate. The whole of this portion exposed in the photograph is the equivalent of the foot of a snail.

CHAPTER XIII

PHYLUM ARTHROPODA

CLASS CRUSTACEA

"Insects of the Sea"

THE Arthropoda includes a variety of animals having two things in common. There is an external skeleton, formed by a hard cuticle, composed of a series of segments enclosing the body but having the cuticle soft and pliable at the joints. There is typically a pair of simple jointed limbs to each segment but they may be reduced in number, or modified to form walking legs, swimming legs, weapons of offence or defence and, those near the front end of the body, jaws. Usually one or two pairs at the extreme front end are converted into feelers or antennae.

Since the cuticle is not a living tissue it cannot grow and, since it encloses the muscles and other soft parts of its owner completely, growth in size can only take place in a series of moults. At each moult the outer skeleton is shed, leaving the former inmate with a soft skin. A short period of rapid increase in size follows, and in a little while a new cuticle is grown within which the animal continues to feed and store up the potential for new growth against the next moult.

In the Arthropods, which represent the highest invertebrates, we meet for the first time many-jointed limbs, of diverse forms, giving much increased power of locomotion and greater adaptability. For the first time, also, we find jaws, but, unlike those of vertebrates, their action is not up and down but from side to side. The possession of a rigid cuticle made air-breathing comparatively easy of attainment, leaving the way open for a successful invasion of the land. And all these things, together with the increased elaboration of the nervous system and sense-organs, paved the way to more active and varied ways of life, so that it is not surprising to find the various members of the Arthropoda adapting themselves to an almost infinite number of situations in water, on land and in the air.

The phylum Arthropoda is divided as follows:

Class Crustacea, with the head not distinct from the thorax, two pairs of antennae, legs usually numerous and different in form.

Class Protracheata, containing a relatively few species of archaic invertebrates of specialized form.

Class Myriapoda, having a distinct head, one pair of antennae and numerous legs all alike.

Class Insecta, with the body divided into head, thorax and abdomen, bearing one pair of antennae and three pairs of legs. Usually with one or two pairs of wings in the adult, springing from the upper side of the thorax.

Class Arachnida, having the head fused with the thorax, to form a cephalothorax, without antennae, and with four pairs of legs.

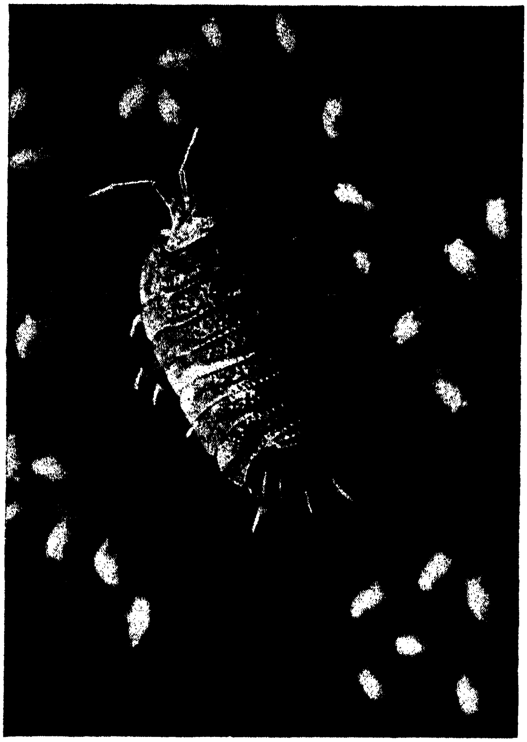
Class Crustacea

The part played by the Crustacea in the sea is similar to that taken by insects on land; and just as few insects are found in the sea, so the Crustacea are represented on land by the rare exceptions like the woodlice and the land crabs. In the sea they range from just above tide-marks down to the deepest abysses of the ocean. Some of them form a considerable part of the floating life, or plankton, on which so many of the sea's inhabitants are dependent. These are, however, the smallest of them. The larger, more familiar, include the crabs, lobsters, prawns and shrimps, even the barnacles, which from their appearance might be thought to be more closely related to the Mollusca.

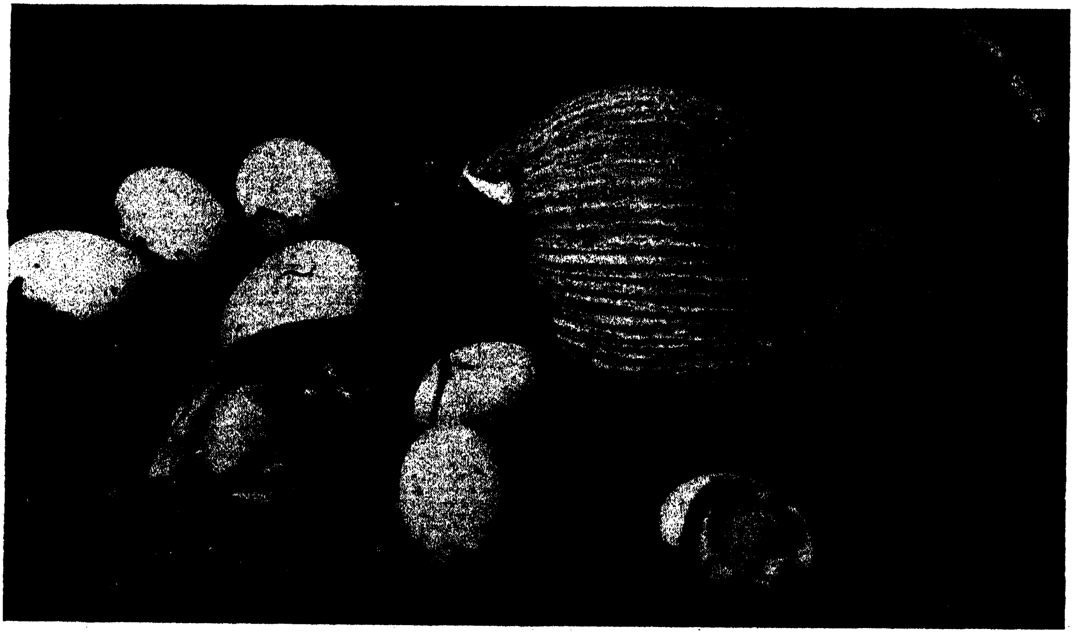
General characteristics

There is in this group a greater diversity of form than in the other groups of Arthropods to be considered later. As a consequence it is not easy to summarise the characteristic features. In general terms they may be described as arthropods that are mainly aquatic, breathing by gills or through the general surface of the body, possessing two pairs of feelers, or antennae, on the front part of the head, at least three pairs of jaws and a variable number of swimming or walking legs. There is one feature common to most branches of the Crustacea which is distinctive, the nauplius larva. This has an oval body with three pairs of limbs on the underside, around the mouth, and a single eye in the middle of the head end; and many forms which in the adult are very unlike each other begin life as a nauplius.

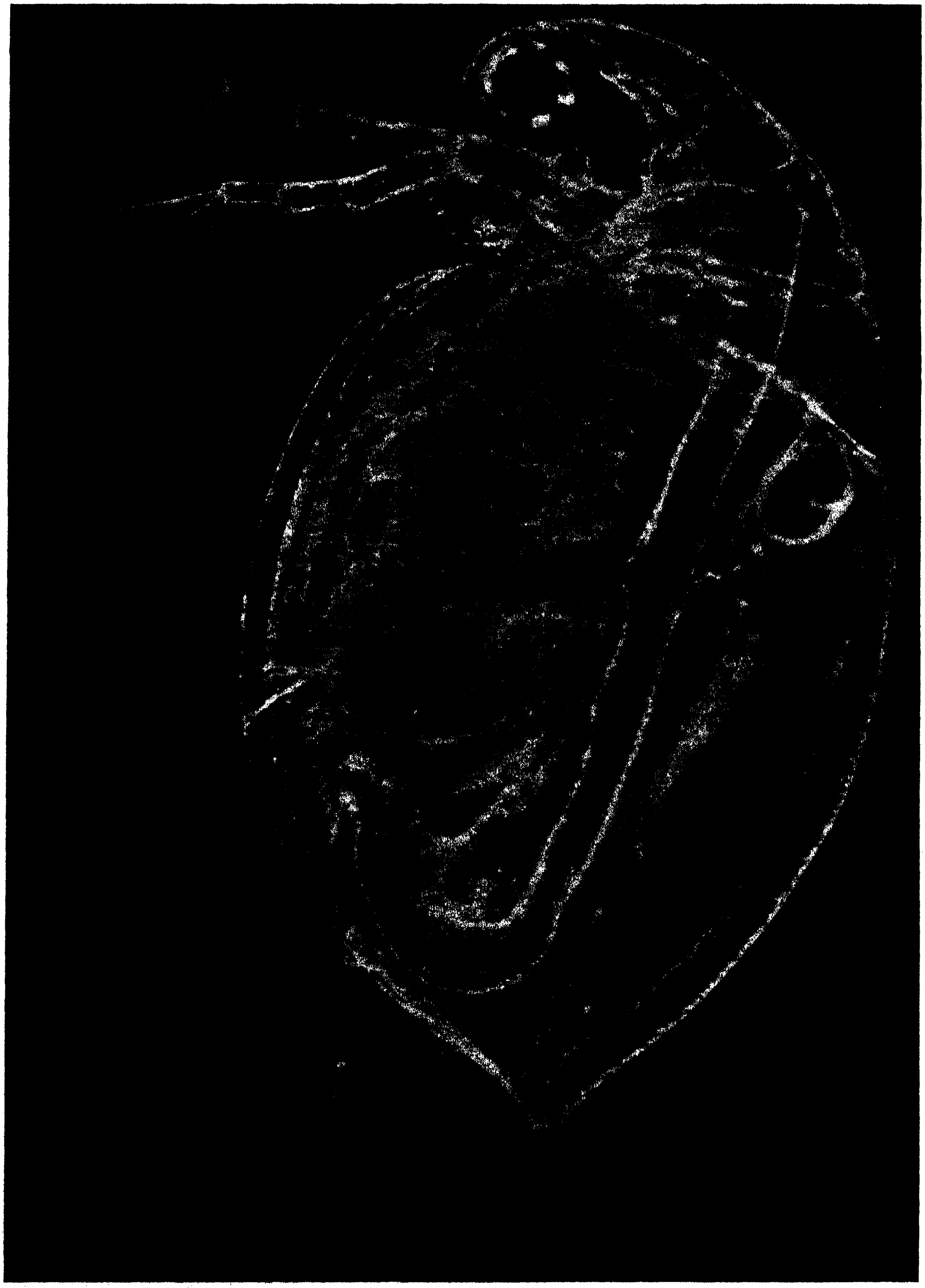
Vivipary and Ovipary. There are two main ways of producing offspring: by eggs which hatch after extrusion from the body, and by producing the young alive, the development having taken place inside the body of the parent. The first is designated ovipary, and the second vivipary; and a species is referred to as oviparous or viviparous according to which of these methods is employed. There is, however, a condition known as ovovivipary, found especially in reptiles and some sharks, where a well-developed shell is formed, but the egg is hatched within the parent and the young is extruded alive.



Vivipary. The Woodlouse, or Slater *(Porcellis scaber)*, surrounded by some of her new-born young.



Ovipary. The Brazilian Land Snail *(Borus oblongus)* with its eggs, one of which has just hatched.



Daphnia, one of the water-fleas. The intestinal tract can be clearly seen with, behind it, the brood-chamber containing an egg. (Magnified 150 times.)

The class is sub-divided into:

- Sub-class Branchiopoda (Fairy shrimps, Brine shrimps and Water-fleas);
- Sub-class Ostracoda;
- Sub-class Copepoda (including Fish-lice);
- Sub-class Cirripedia (Barnacles);
- Sub-class Malacostraca (Crabs, lobsters, prawns, shrimps, woodlice).

The last sub-class includes the larger and better-known Crustacea, but the other classes have a strong interest and one of them, the Copepoda, or copepods, has a tremendous importance in the economy of both the seas and the fresh waters.

Sub-class Branchiopoda

The Fairy Shrimp, occasionally found in ponds and rain puddles, has the body divided into segments like an Annelid worm. Each of the first eleven segments bears a pair of fin-like feet, and the tail is forked. There is the usual pair of antennae, and a pair of stalked, movable eyes. There is a good chance of the ponds and puddles drying up in the summer and, when this happens, the eggs lie in mud ready to hatch as soon as the rains come. A close relative, the Brine Shrimp, is found in salt lakes, such as the Great Salt Lake at Utah, and, indeed, requires a high concentration of brine to live successfully.

The Water-fleas, abundant in ponds and ditches, have the body enclosed in a bivalve shell. From this the head protrudes bearing a pair of branched antennae and a single, median eye. The four to six pairs of legs are in constant motion, causing a water current bearing a supply of food particles to pass through the shell. These crustacea are all of small size and, partly because of the ease with which they can be obtained and partly because, being transparent, every organ of the body and every detail of their behaviour can be readily observed, they are favourite subjects for examination with the microscope.

Eggs are laid in a brood pouch, formed by a space between the body and the shell, and these develop without being fertilised. During the greater part of the year the water-fleas are all females, but at certain seasons males appear and fertilised eggs are produced.

Sub-class Ostracoda

These, which have a bivalve shell like the water-fleas, also the protruding head and antennae, are nearly all microscopic in size and are abundant in both sea and freshwater. They breed parthenogenetically and one culture has been kept for well over thirty years without a single male having been seen.

Sub-class Copepoda

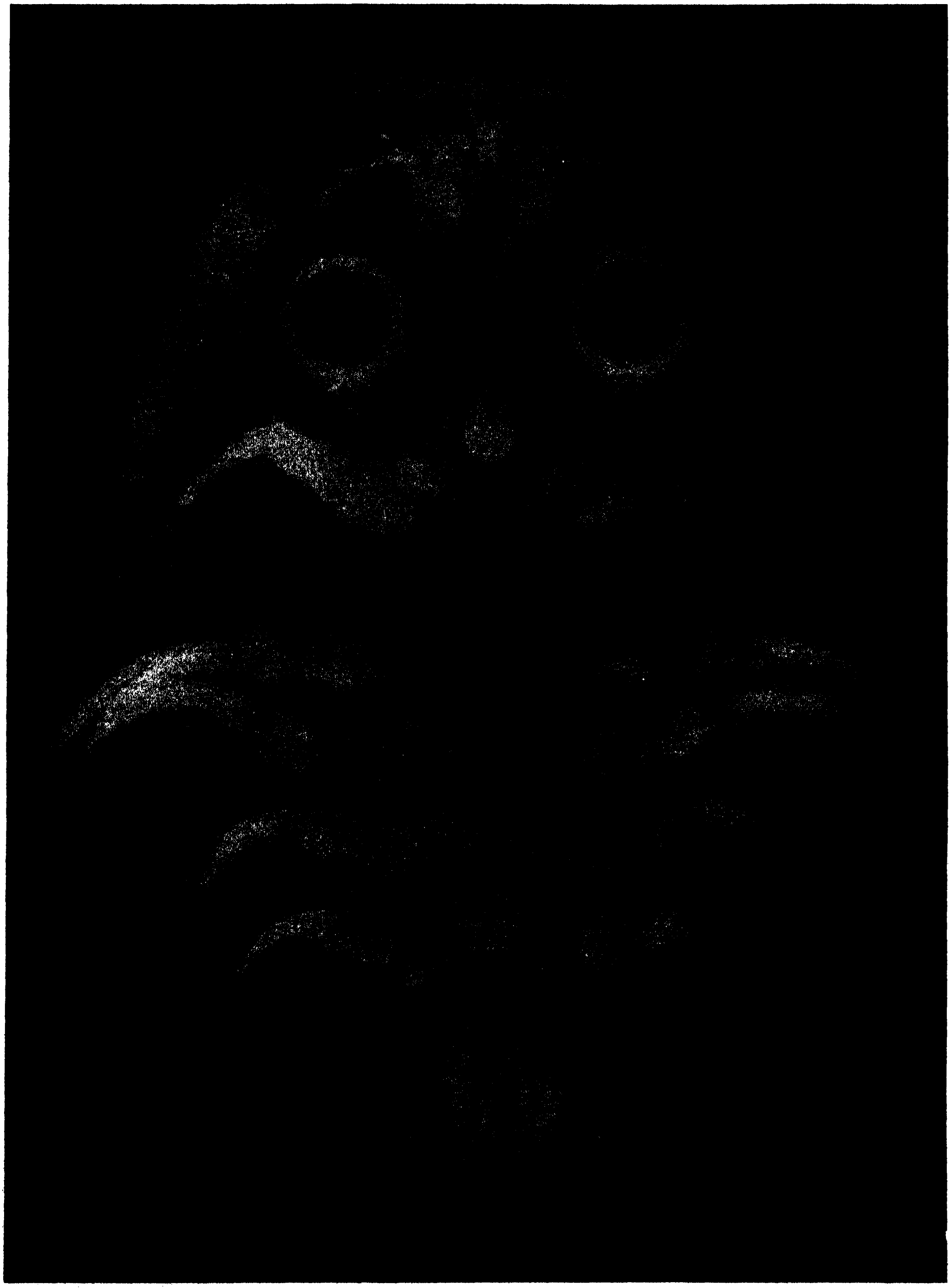
It is difficult to find an exact parallel on land with the part played by the copepods in the economy of the sea, and for this reason it is not possible to draw so vivid a picture of their importance as the case merits. They swarm in their countless billions in the surface waters of the oceans, feeding on the microscopic plants, and in turn themselves form the food of many kinds of fish, especially mackerel and herring, or even of the huge whalebone whales.

The planktonic copepods have a fusiform body, ending in a forked tail, with two pairs of antennae in front, one pair of which is very long. They swim by means of several pairs of swimming legs. In addition to those found in the sea there are others in freshwater, the beautiful *Cyclops* (see p. 23) being the best known.

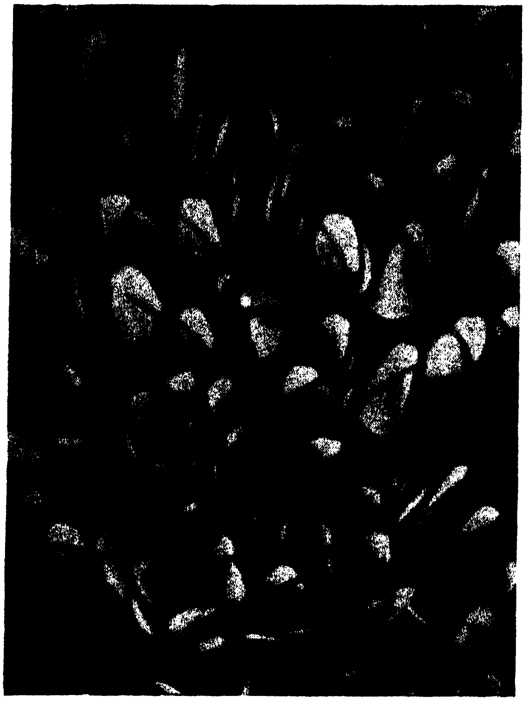
In addition to the free-swimming copepods, there are many which live as parasites on other aquatic animals and are known collectively as fish-lice. Some are not very different from the free-living species except that the body tends to be flattened and they have hooked claws by which they cling to the bodies of their hosts while sucking their blood. Others have degenerated, in relation to their parasitic habit, until they are no more than shapeless, almost limbless sacks.

Sub-class Cirripedia
(Barnacles)

There are three main kinds of Barnacles, the Stalked Barnacles, Acorn or Rock Barnacles and certain parasitic and highly modified forms. The Stalked Barnacles are the most familiar and can best serve as our example, although the Acorn Barnacles are much the most common.



Argulus, the fish-louse, one of the Crustacea which has become an ectoparasite on fish, to which it adheres by the two suckers near the front end of the body. Having well-developed swimming legs it is, however, capable of swimming on its own when necessary. (Magnified 50 times.)



A mass of goose barnacles growing on timber immersed in sea-water. (One half natural size.)

There seems little resemblance between a barnacle and other Crustacea, for example, a crab or shrimp. The body is enclosed in a shell composed of five hinged plates, carried on a stout, muscular stalk. At one side of the shell is a slit from which can be protruded six pairs of long, curled feet, each having two branches fringed with bristles. These can be spread out, as a sort of casting net, to sweep the water for minute floating animals. The stalk represents the head, and a pair of antennae can be discovered in the cement fixing the barnacle to its support.

The first stage in the life of a barnacle is the nauplius larva, which changes later into a cypris larva, very like an Ostracod, in which six swimming feet and a pair of antennae ending in suckers can be seen. Up to this stage the barnacle is free-swimming, but at a certain stage it settles down, attaches itself by the antennal suckers, casts off its bivalve shell and undergoes the remarkable change into an immobile barnacle.

Sub-class Malacostraca

(Woodlice, Sandhoppers, Prawns, Shrimps, Crayfishes, Lobsters, Crabs)

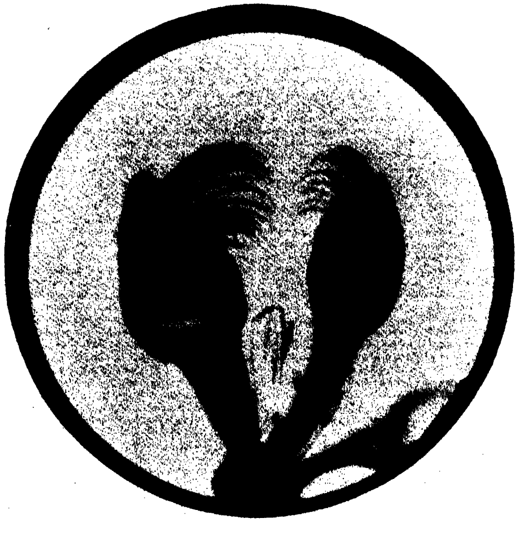
The best-known and most readily recognised members of this sub-class include the marine shrimps, prawns, crayfish, lobsters and crabs. There are, nevertheless, a number of others which for the sake of completeness it is proposed to mention, though briefly. Their chief interest rests, however, in their primitive structure, since they furnish interesting evidence as to a probable line of evolution of the more highly-developed crabs, and help to illustrate the relationship between the forms already considered and those yet to be described.

In the Malacostraca there is an obvious division of the body into a thorax and an abdomen, the former bearing eight pairs of appendages, the latter having six pairs of appendages and an end-piece or telson.

The Sub-Class is subdivided into five divisions:

Division Phyllocarida, probably the most primitive Malacostraca and closely related to those whose fossil remains are found in the Cambrian rocks.

Division Syncarida, or Mountain Shrimps.



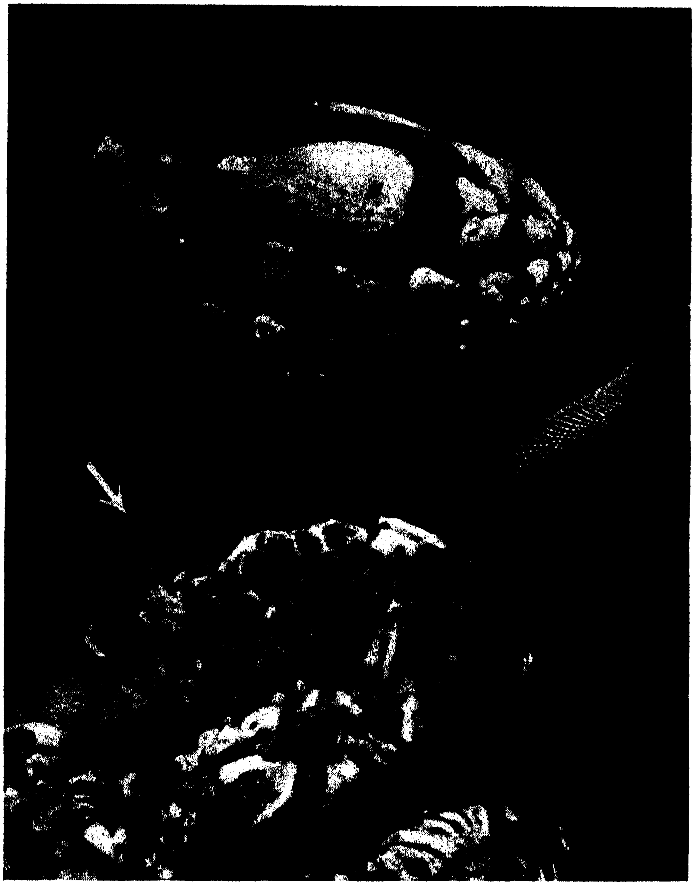
Photomicrograph of two barnacles *(Lepas)* in which the soft body can be seen through the shell, and showing the legs no longer used for locomotion but for sweeping food into the mouth.

Division Peracarida, including Woodlice, Freshwater Shrimps and Sandhoppers.
Division Eucarida, including Marine Shrimps, Prawns, Crayfish, Lobsters and Crabs.
Division Hoplocarida, or Mantis Shrimps.

Division Phyllocarida

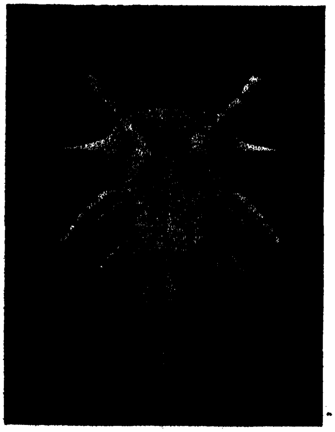
The members of this division, of which *Nebalia bipes* is a typical example, have a bivalve shell like the Ostracoda and certain of the Branchiopoda, leaf-like gills on the thoracic legs, like the Branchiopoda, yet have the thorax and abdomen typical of the Malacostraca. It is they that approximate closely to the Cambrian fossil Malacostraca and suggest what the very early ancestors of the Sub-class must have looked like.

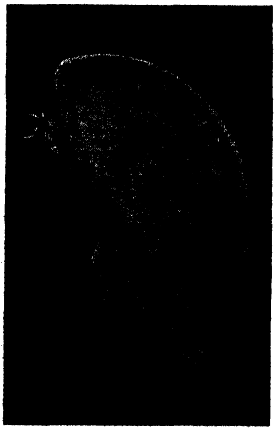
Division Syncarida
Order Anaspidacea



A stalked goose barnacle with the feet protruded and, below, a group of acorn barnacles, sessile or unstalked. The arrow points to the feet protruding from one of the acorn barnacles. (Twice natural size.)

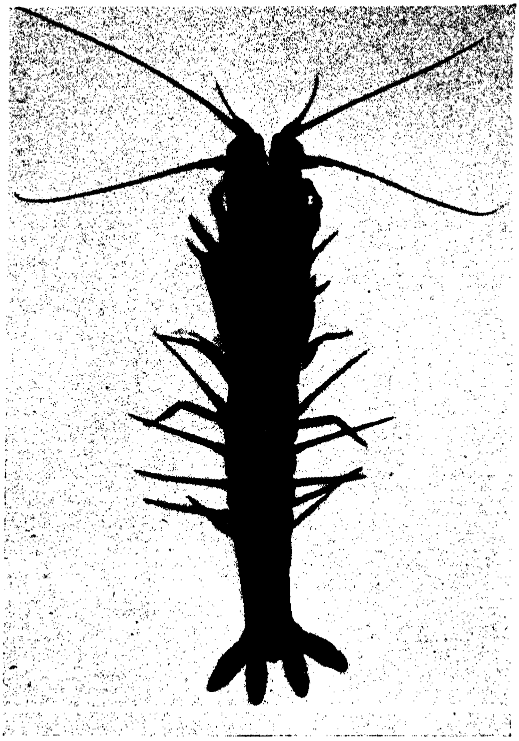
Although such a small order, consisting of a half-dozen species only, it has an unusual interest. The first species discovered, in mountain streams of Tasmania, was *Anaspides tasmaniae*, a prawn-like creature, some three inches long, having a fully segmented body, without a carapace. The Mountain Shrimp is,





The life-history of the typical Crustacean starts with the nauplius larva, which is succeeded by the cypris. In some of the more advanced Crustacea the nauplius is missing, the life-history having become telescoped. The free-swimming nauplius shown here is of *Sacculina*, but it is also very like that of the barnacles and, with minor variations, like those of many other Crustacea. (Magnified 100 times.)

On the right is the cypris or second larval stage of *Sacculina* (or of a barnacle). At this stage it resembles closely the Ostracoda and furnishes an example of the recapitulation of a racial history in development. The Ostracoda are primitive Crustacea and there is little doubt that some of the more highly-organised Crustacea were developed through ancestors closely resembling them.



Anaspides tasmaniae, a primitive Mountain Shrimp, living in the rocky pools of the mountain streams of Tasmania.

with little doubt, a survivor of an ancient group once more widely distributed and bears a remarkable likeness to fossil remains found in the Carboniferous. Other species also live in Australia.

Closely related to them are several species, only one twenty-fifth of an inch long, found in caves and wells of Europe and Malaya.

Division Peracarida
(Oposum Shrimps, Woodlice, Freshwater Shrimps, Sandhoppers)

These are sometimes called the Pouched Shrimps because the females have a brood-pouch on the underside of the thorax, formed by a series of overlapping plates attached to the bases of the legs. The eggs are laid in the pouch and undergo their development there. The young leave the pouch differing little from the adult except in size.

Order Mysidacea
(Oposum Shrimps)

These are of small size, found in the sea, often in rock pools, but some are found in freshwater pools. They are shrimp-like, with a conspicuous brood-pouch, whence the name Oposum shrimps, the Oposum being a mammal with a marsupium or brood pouch.

Order Cumacea
Order Tanaidacea

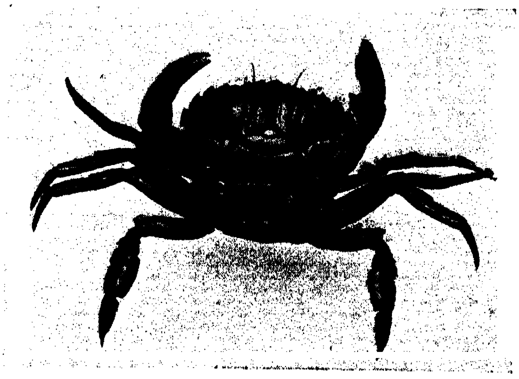
The members of these two orders are of very small size, found in the sea, mostly burrowing in the mud, and while they are of considerable importance in the general economy of the sea, it is not necessary to enter into further details in a general work such as this.

Order Thermosbaenacea

This order contains only a single species, living in the scalding hot water of a mineral spring in Tunis.

Order Isopoda
(Woodlice or Sow-bugs)

This is by far the predominant order of the



The European Shore-crab parasitised by *Sacculina*, a crustacean which settles on it and, from a typical cypris larva, undergoes degeneration until it is nothing more than a bag of reproductive organs throwing root-like processes into the crab's body, from which it draws its nourishment. The *Sacculina*, which is hermaphrodite, can be seen lodged between the abbreviated abdomen of the crab and its thorax.

Peracarida and comprises a large number of genera and species. All have, however, a characteristic form. They are flattened from above downwards, are without carapace, and have a segmented body. The abdomen is short and the abdominal appendages are plate-like, serving as gills to those Isopods living in water, the great majority of which are marine. In this order we find the only truly terrestrial crustacea, the woodlice.

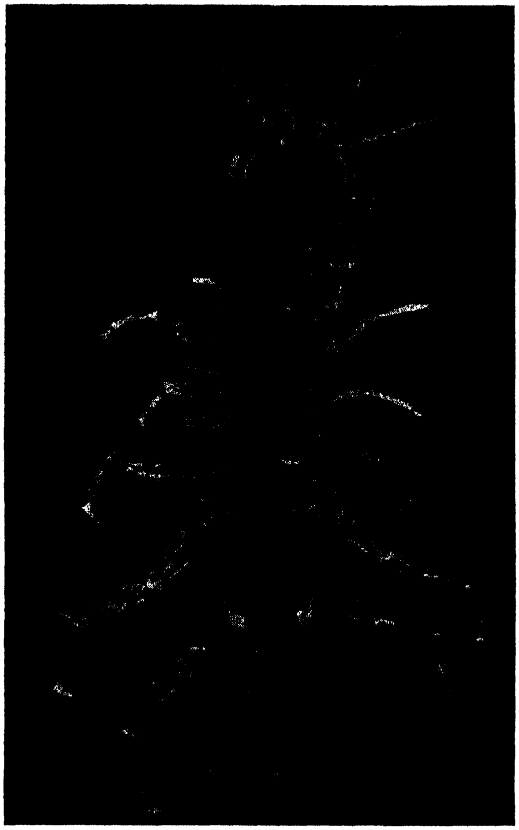
Some species, such as those belonging to the genus *Idotea*, live just above high-tide mark, in the area splashed by the spray from the highest waves, and although regarded as marine are on the way to becoming terrestrial. The aquatic forms breathe through the abdominal plates, but the terrestrial woodlice breathe through tufts of tubes, located as white spots on the undersurface of the abdomen.

Some of the Isopods, although of comparatively small size, are savage devourers of fish, and yet others will bite human beings bathing in the sea. It is not surprising, therefore, that others, taking this habit further, have become parasitic on fish, clinging to them and sucking their blood. It is of interest to note that in some of these there is a change of sex in the course of their lives. When young they are actively swimming males, but when they settle on the fish they become females. The most advanced parasitism is found in forms like *Bopyroides hippolytes*, which lives in a tumour-like swelling on the carapace of a prawn. It is the female which causes the swelling, the male being considerably smaller in size and parasitic on the female.

Order Amphipoda
(Freshwater Shrimps, Sand-hoppers)

The Amphipods differ from the Isopods in having the body laterally compressed, and thoracic limbs varying markedly in appearance. The four anterior pairs of thoracic limbs are directed forwards, the three posterior pairs directed backwards. They include freshwater shrimps, important as food of such fishes as trout, and sandhoppers, or sand-fleas, which can be seen jumping about in quantities on seaweed or in the sand at or near high-water mark. Many other Amphipods are found in the plankton, where they form the food of marine fishes.

One family of Amphipods, the Cyamidae, or Whale-lice, live on the skin of whales. They are unable to swim at any stage in their life-history, and are transmitted from one whale to another by contact only.


The freshwater Isopod, *Asellus aquaticus*, closely resembles a woodlouse. Common throughout Europe, there are closely related species equally abundant in North America.

Division Eucarida

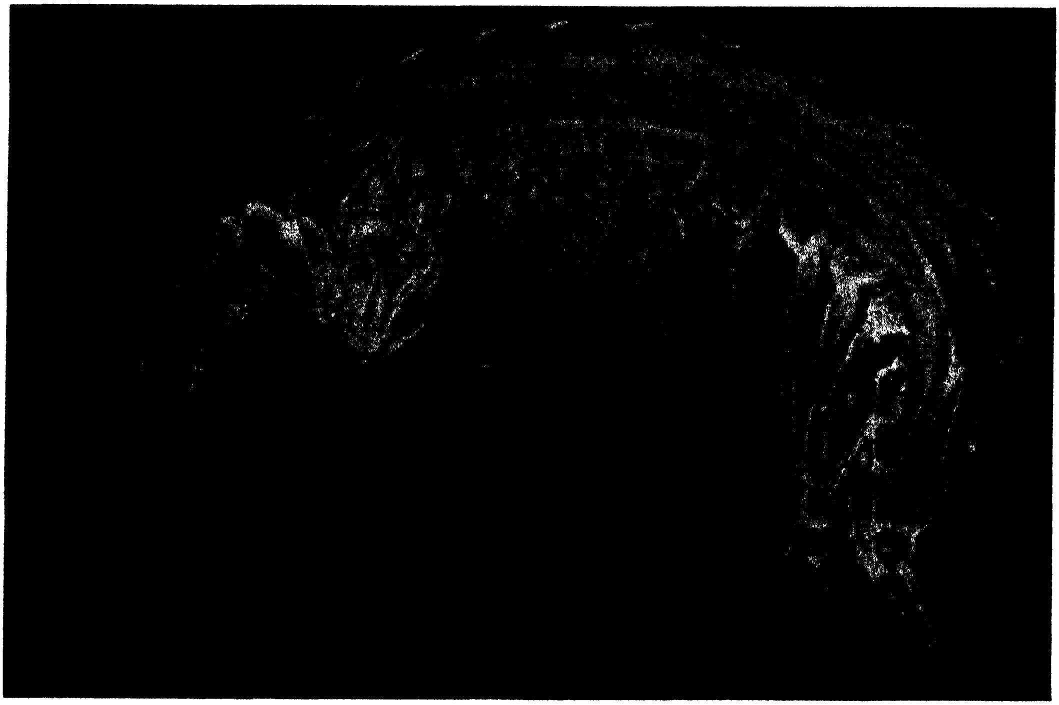
This comprises two orders of very unequal size, the Euphausiacea and the Decapoda, the latter containing the great variety of Shrimps, Prawns, Lobsters and Crabs, which represent to most people the typical Crustacea.

Order Euphausiacea

The Euphausids are shrimp-like, small, very like the Oposum Shrimps but lacking a brood-pouch. They are found in countless millions in the plankton of the sea and form the food of many fishes and also of the whalebone whales.

Order Decapoda

Although the more primitive Decapods resemble closely the Euphausids, and some of the other, more primitive Crustacea, they are distinguished from them by the fact that the first three pairs of thoracic limbs are modified to form jaws, known as maxillipeds. Of the remaining five pairs (whence the name Decapoda or "Ten legs") it is usual for one or two pairs to end in claws, the chelae, to be used for seizing food. The gills are at the bases of the thoracic legs and on each side are enclosed in a gill-chamber formed by the overlapping side-plates of the carapace.



Gammarus pulex, the Freshwater Shrimp, a typical Amphipod in which the first few pairs of legs are directed forwards, and those that follow directed backwards. It is closely related to the sandhoppers or Sand Fleas so common on the shore. (Magnified 30 times.)

A convenient sub-division of the order is:

Sub-order Macrura. Including the more primitive Decapods, the Shrimps, Prawns, Crayfishes and Lobsters, with a long abdomen and abdominal limbs forming swimmerets, by which the animals move themselves through the water.

Sub-order Anomura, hermit-crabs.

Sub-order Brachyura, or crabs, with a small abdomen folded under the thorax.

Sub-order Macrura

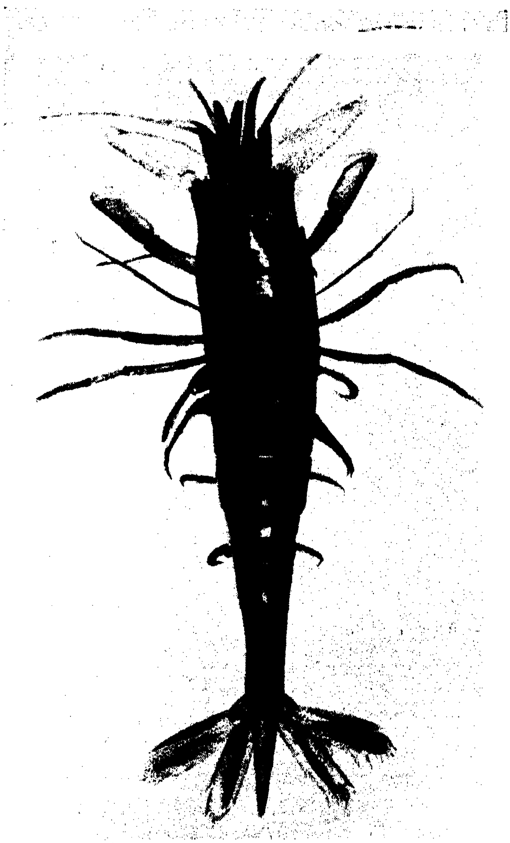
(Macro – long, ura – tail)

(Prawns, Shrimps, Crayfishes, Lobsters)

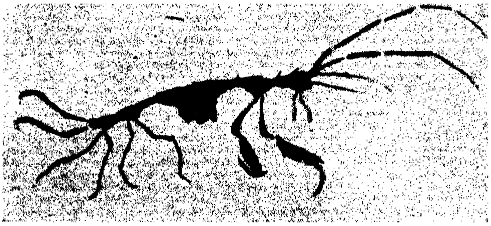
There are several thousand species of Crustacea included here, and since the names Prawn and Shrimps, and to a lesser extent Crayfish and Lobster are used often indiscrimately, it is not easy to be definite in speaking generally about them. Strictly speaking a prawn has a strong, laterally-compressed abdomen with a prominent serrated rostrum projecting forward from the centre of the carapace. Prawns are abundant in all tropical and temperate regions, both in fresh and salt water, and are extensively used as food. The common species of Europe and North America range from one to six inches long, but tropical species may be up to two feet. Shrimps, on the other hand, have a somewhat flattened abdomen and the rostrum is reduced to a small spike. They have the habit of seeking shelter in the sand when alarmed, burying themselves so as to leave only the antennae exposed. The antennae in both prawns and shrimps are long and whip-like and serve as organs of touch, and both animals swim backwards with a movement of the tail-piece. Their food is decaying animal and vegetable matter.

A Crayfish in berry.

One species which merits special attention is the small Aesop Prawn, *Hippolyte varians*, found in rock-pools. This has the ability to change its colour to match the colour of the seaweed among which it lives. If on a brown seaweed it is coloured brown, if on red it is red, and so on. Should it become dislodged it will seek a seaweed of the same colour as its body. If this is not possible it will change its colour to match the new surroundings in two to three days.

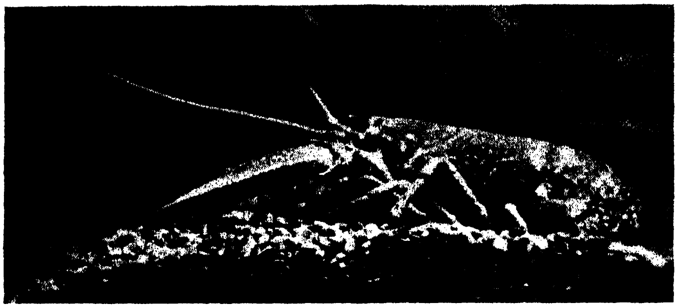


The Common Shrimp of Europe *(Crangon vulgaris)*.



***Protella phasma*, one of the Caprellids or Skeleton Shrimps, lives among seaweeds. The thorax is elongated and the abdomen reduced to a tiny vestige at the end of it. (Magnified 12 times.)**

The rest of the Macrura, the lobster-like forms, are larger in size and the horny exoskeleton is impregnated with lime salts to form a heavy armour. There are three main groups. The first of these, the Eryonidea, are confined to the deep seas. They are blind, the eyes being reduced to the stalks only. Their main interest is that they were known as fossils found in rocks of the Secondary period before being found living. The next group, the Scyllaridea, or Spiny Lobsters, are devoid of pinching claws, but to compensate for the lack of weapons of offence the body is beset with spines and the antennae are well-developed, stout and longer than the body. Living among rocks, the antennae give ready warning of the approach of



The European lobster *(Homarus vulgaris)*.

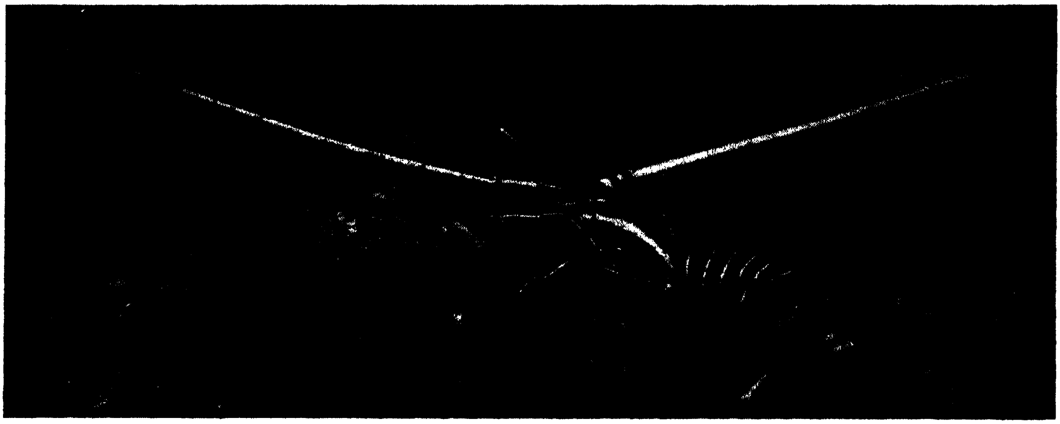
enemies. A well-known example of this group is the Langouste of the French coast, also known as the Rock Lobster or Sea Crawfish.

The third group, the Nephropsidea, includes the true lobsters and the freshwater crayfishes. In addition to the larger size and the stouter quality of the external skeleton, they are characterised by the possession of large crushing claws. The habits are similar to those of the Spiny Lobsters. When sheltering the antennae give warning of the approach of an enemy, and the large claws can be used effectively as weapons of defence. The food is mainly decaying animal or vegetable matter, which is held in the large claws and torn to pieces by the jaws. In some lobsters, the large claws are armed with blunt knobs used for crushing the shells of mussels and other such molluscs.

With such a rigid external skeleton growth would be impossible but for a process of moulting or ecdysis. The hard shell splits down the back and the animal withdraws itself. It then has a soft skin and must hide until it has hardened up. While the hardening is in progress the animal grows larger. A lobster sheds its shell eight times the first year, five times the second, three times the third year. Thereafter growth is slower, the males moulting twice and the females once a year.

Sub-order Anomura
(Hermit crabs)

The typical members of this sub-order have the habit of living in the empty shells of gastropod molluscs and the shape of the body is modified accordingly. The abdomen is soft and spirally-twisted to fit into the shell, and the tail-piece is modified to anchor the hind end of the body inside the shell. The claws are unequal in size, the larger being used to stop up the entrance to the shell when the crab retires within. The next two pairs of legs are long and slender and used for crawling, while the following two pairs are short, with roughened pads to grip the inside of the shell. Another significant change is in the



The Rock or Spiny Lobster, *Palinurus*, one of the Langoustes of the French lobster fishery. This one lives in the seas off Madeira.

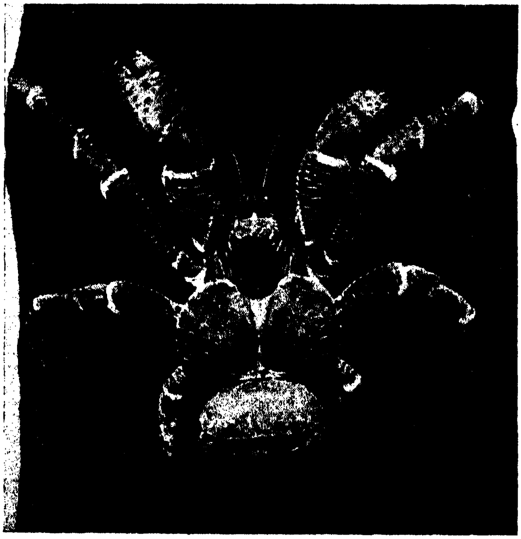
swimmerets, which are confined to one side of the abdomen only, more conspicuous in the female than the male, and used for carrying the eggs.

As the hermit crab grows it must change over to a new and larger shell. At such a time a new shell is selected, the crab carefully exploring the inside with its claws before making the change.

Other hermit crabs, of the genus *Coenobita*, found on tropical beaches, often travel far inland, but return to the sea to breed. These Land Hermits often climb trees, but not to the extent of the large Coconut or Robber Crab (*Birgus latro*) which climbs well up into coconut palms. This latter species does not need a borrowed shelter for the abdomen, which is bent under the thorax, and is protected by shelly plates.

Several other related forms also do not use the portable shelters, but develop spines on the shell, such as the Stone Crabs and Porcelain Crabs, or hide under stones, as the Squat Lobsters, or burrow in the sand, as the Mole Crabs of the tropics, with their legs spade-like and adapted for digging.

The Giant Hermit Crab of the tropical Atlantic lives in a large whelk-shell to protect its soft abdomen.



The Robber or Coconut Crab *(Birgus latro)* of Christmas Island.

Sub-order Brachyura
(Crabs)

The True Crabs usually have the carapace broader than long, with the abdomen reduced to a small flap folded under the thorax, the swimmerets being developed in the female only and used for carrying the eggs. The jaws are enclosed in a conspicuous mouth frame formed by the flattened, door-like third maxillipeds. The young, newly-hatched larvae have, usually, the form known as the zoea, which changes later to the megalopa, having the general form of the adult except that the abdomen is large and not folded, and the swimmerets are used in swimming.

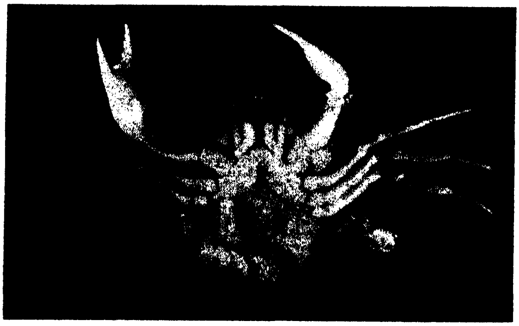
The number of species is large and the variation in form and habit very diverse. The Sponge Crabs usually carry a sponge or other marine animal on the back for concealment. The Sand Crabs bury themselves in the sand and have a special apparatus formed from the mouth-frame which enables them to breathe with only the tip of the carapace exposed. The Spider Crabs have special hooked hairs on the carapace on to which fragments of seaweed and other organisms such as hydroids and sponges are attached to give concealment. The Giant Spider Crab has

A Squat Lobster from Madeira.

a carapace over a foot wide, and its long claws when fully extended may span eleven feet.

There are crabs that resemble stones, corals and other features of their habitat. Others bury themselves in the sand. The tiny Pea Crabs live in the mantle cavities of mussels and oysters or in the gut of sea-urchins or starfish. Another species, *Melia tessellata*, of the Indian and Pacific Oceans, carries a sea-anemone in each claw for protection. In spite of the heavy armour and formidable claws the crabs in general show a wide and interesting range of adaptations in shape or habit all directed to one end, protection by concealment (see p. 238).

Although the Brachyura are typically marine, many tropical species show a marked amphibious habit. The swift-footed Crabs of the genus *Ocypoda* live in burrows in the sand above high-tide mark. The Calling or Fiddler Crabs inhabit the mud flats and salt marshes. The females are of normal build but the males have one claw much larger than the other, often it is larger than the body. All these, like the Land Crabs, are able to breathe air and live out of water, but are not truly terrestrial since they must return to the sea to breed.

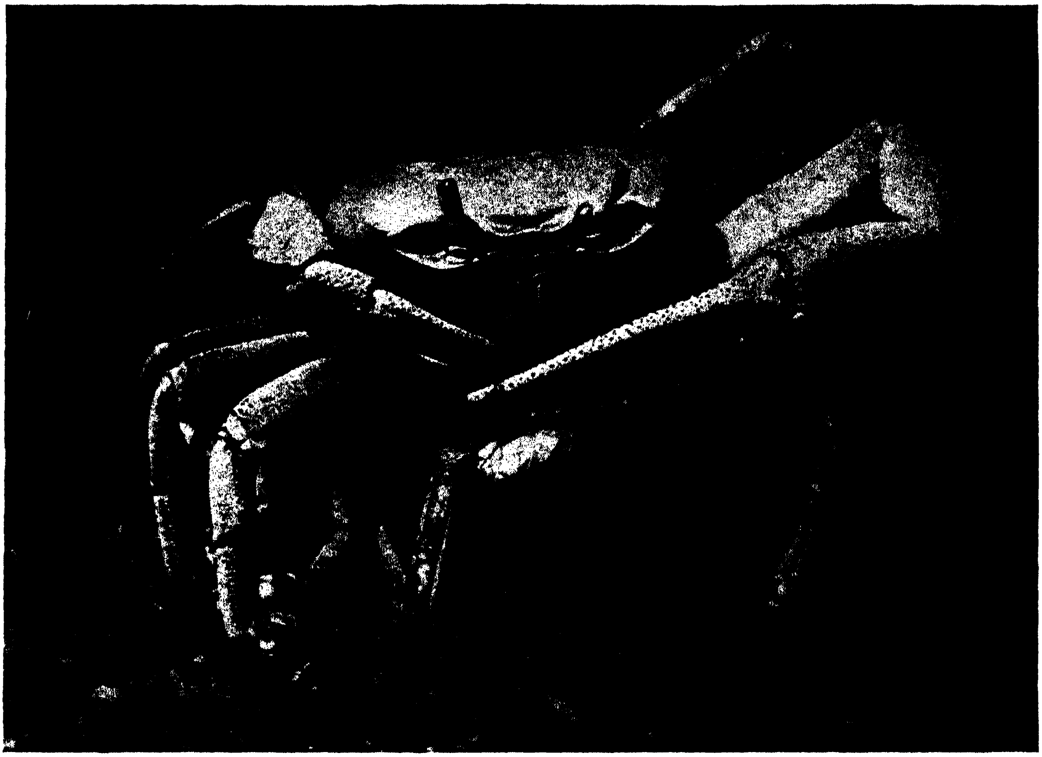


The crab *Portunus depurator* in berry. The mass of eggs is carried by the female on the undersurface of the body.

A Spider Crab *(Maia squinada)* decorates its back with small pieces of seaweed and so becomes almost indistinguishable from its surroundings.

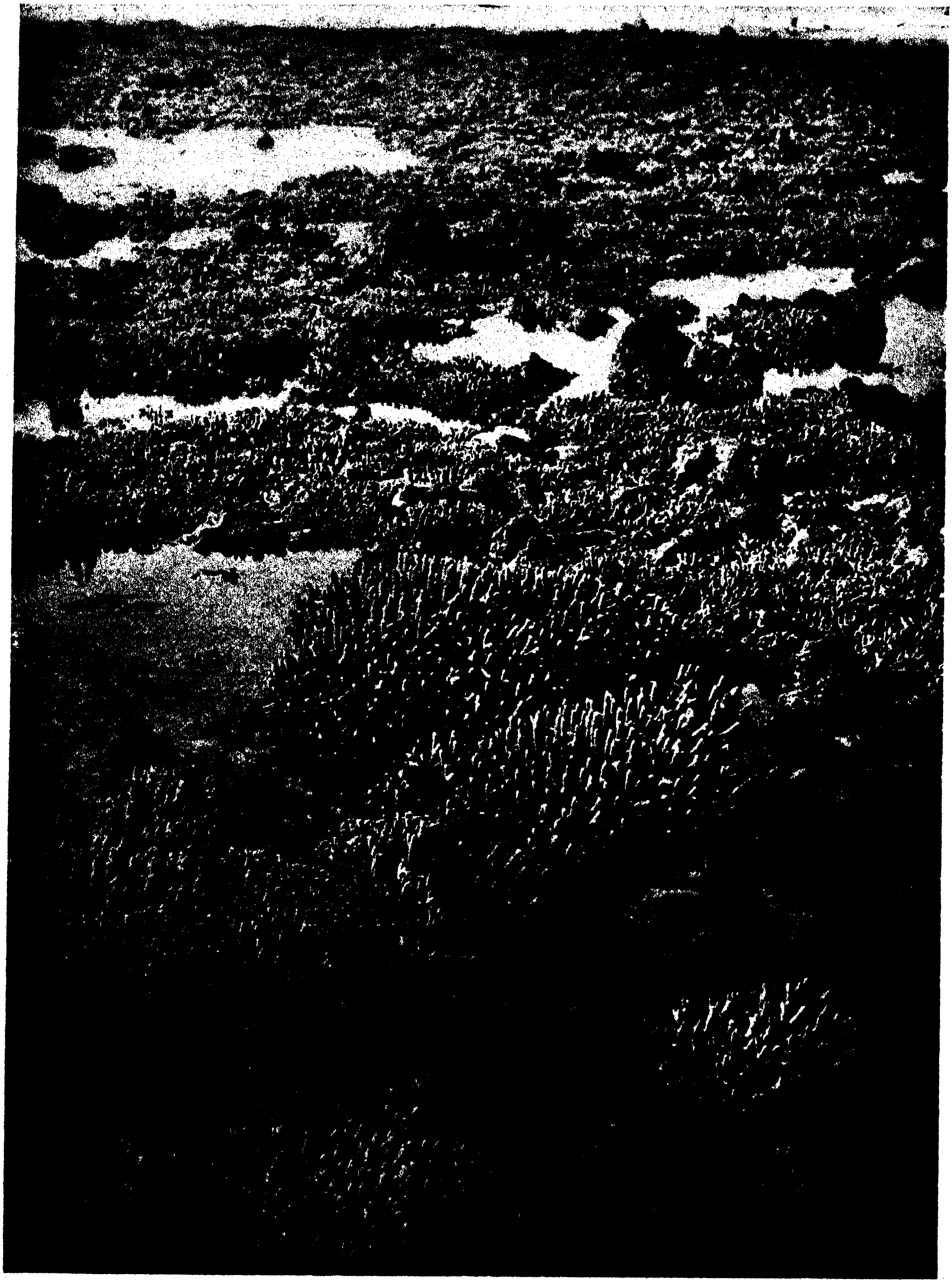
Division Hoplocarida
Order Stomatopoda
(Mantis Shrimps)

These are flattened, with a large abdomen and conspicuous tail-piece, with carapace small, leaving the last four thoracic segments uncovered. The head segments, unlike those of any other Crustacea, are movable. The large pincer-like claws are replaced by strong legs the last segment of which is armed with strong teeth and closes on the preceding segment like the



A Land Crab *(Cardesoma armatum)* of West Africa. Although living on land it must return to the water to breed.

blade of a pocket-knife; in this, as in their general behaviour they bear a fair resemblance to the Praying Mantis, among Insects. They live in crevices in the rocks or in sandy burrows seizing passing animals with a swoop from the claspknife-like legs.



A portion of a coral reef showing the crowded growths, to which must be added many other animals living on or among the corals in order to appreciate the dense populations inhabiting such waters.

CHAPTER XIV

BIONOMICS

This is a suitable stage at which to consider the associations of animals, the significance of form and the methods of concealment as exemplified by the crabs

A STUDY IN OVERCROWDING

A CORAL reef teems with life. The water is crowded with irregular masses of limestone, peopled with myriad polyps, with here and there the more symmetrical forms of rounded or tree-like corals. The spaces between the many-hued corals are filled with delicate sea-fans, orange or red, with multi-coloured sea-anemones and sponges of every tint of purple, red, green, and yellow. Within the caverns and gullies, formed by the thickly massed polyps, shoals of small fish seek refuge, and, in addition to those things obvious to the eye, there is life, and still more life, lurking in every nook and cranny of the reef. Prawns, starfish, worms by the hundred find a safe and permanent haven in and among the corals and sponges. There is an overcrowding almost without parallel, and the question of oxygen supply becomes one of great urgency. In fact, such overcrowding would not be possible had the corals to rely on the normal supply of oxygen.

Oxygen in the sea is replenished by two methods; fresh oxygen may be dissolved from the atmosphere, or it may be given off by sea-weeds, in the same way as by land plants. Under normal circumstances, the supply of oxygen in the sea, as on the land, is only of sufficient quantity to support a given amount of life in a given area, and overcrowding leads to suffocation of part, at least, of the population. Corals have solved the problem in this way: there are a number of microscopic plants which have found it beneficial to live permanently in the tissues of the coral polyps and, supplied with an abundant source of food in the waste products of the coral, are able to liberate oxygen at a high rate. The result is that not only do they generate sufficient oxygen for the coral itself, but there is a surplus given off into the surrounding sea. So, the more densely crowded the corals, the more oxygen there is in the water. It is not surprising, therefore, that a coral reef should be the rendezvous of many and diverse creatures.

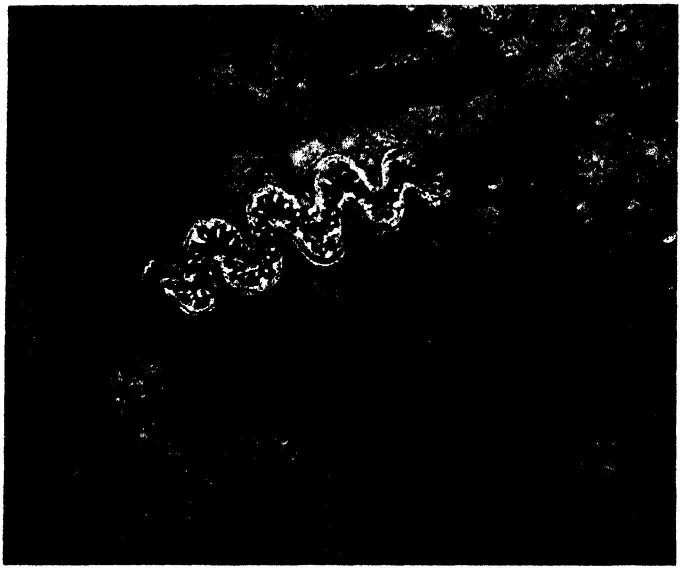
This is one of the many examples that could be cited of the manner in which animals and plants may associate. The association may be casual, temporary or permanent, beneficia or injurious. The subject is dealt with more fully in the next article.

DIFFERENT WAYS OF LIVING TOGETHER

by

DR. BEN DAWES

Animals rarely live in solitude and their associations with other animals and with plants may be fortuitous and causal or, on the other hand, deliberate and intimate. Several different kinds of animals may be thrown together by chance on a single floating log, managing very well on a policy of "live and let live". When one form lives nearly or quite upon another, the association is said to be epizoic, as when hydroids attach themselves to a mussel's shell for anchorage. Hydroids themselves form perhaps the most intimate kind of association, for they exist as colonies of individuals, each colony having a common origin and an organic continuity which enables the individuals to share the same food. Between the extremes of fortuitous epizoic associations and colonial life there are several types of animal partnerships which may be said to involve animals that display simple patterns of behaviour. Symbiosis is a condition in which an animal and a plant—or two animals, or two plants—live together in an intimate relationship of supposedly mutual benefit. Commensalism has the literal meaning of assembling at the same table and sharing the same food and it implies a less intimate association that is not generally advantageous to both members of the partnership. Some zoologists reserve this term for the kind of partnership in which one partner benefits and the other suffers no harm, employing the term mutualism for those instances in which it is known that there is mutual benefit accruing from the partnership. It is a fine distinction and one that is hardly warranted.



The Giant Clam growing among coral. It also contains microscopic plants in its tissues.

Other kinds of animal associations include parasitism, where the benefits are clearly one-sided and where one of the associating forms may be liable to suffer definite harm, and the states known as gregariousness and communalism, which involve higher grades of behaviour that culminate in the complex social organisations characteristic of some insects and mankind, the most highly organised invertebrates and vertebrates respectively.

Symbiosis. The classical example concerns the marine flatworm *Convoluta roscoffensis* and certain microscopic green plants (algae) that exist in its tissues. Other examples concern those invertebrates with similar symbionts, namely *Paramecium bursaria*, a few Radiolaria and Foraminifera and some coelenterates, particularly the reef-building corals. The algae may be green forms (zoochlorellae) as in *Hydra viridis*, or brown forms (zooxanthellae) as in *Hydra fusca*. The whole subject of symbiosis has been reconsidered by Yonge, who has shown clearly that in some instances it implies no more than the existence of algae inside animal cells and that nutritional advantages rarely accrue, though one member of the partnership sometimes gains advantages of other kinds.

All symbiotic lower invertebrates have powers of intracellular digestion and the cells of the gut can, if need be, ingest the algae. This is probably how the partnership arose, for the invasion of the animal from the outside is a rare phenomenon. *Paramecium bursaria* digests its zoochlorellae only when it suffers inanition, but when sunlight and soluble nutrient salts are abundant both partners thrive, even when the animal does not feed on particulate food, so that a truly symbiotic relationship is established. The plant utilizes the excretions of the animal and manufactures starches and proteins, from which the animal draws some at least of its rations.

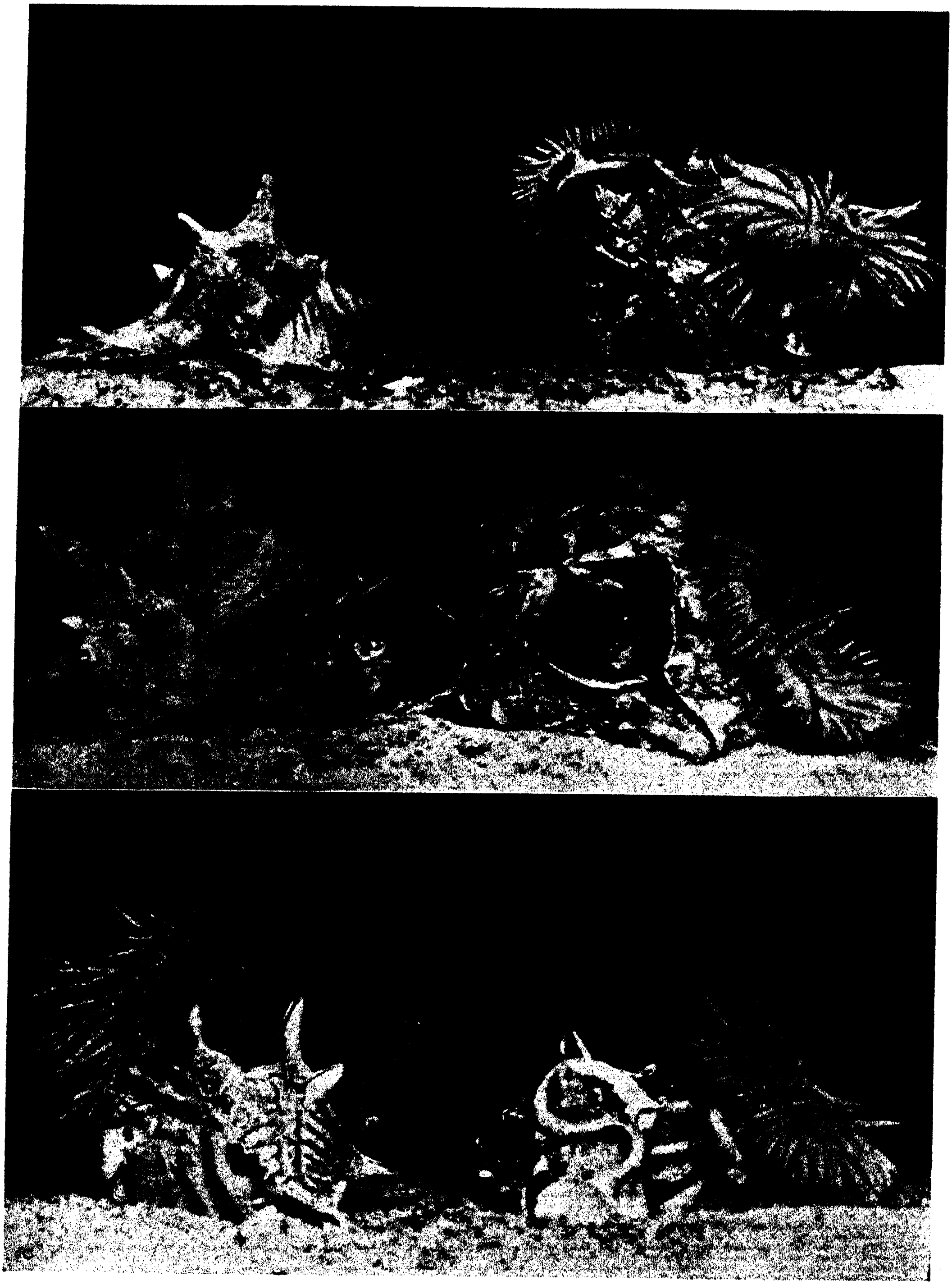
Different conditions prevail in carnivorous animals such as the green hydra, corals, flatworms and some gastropod molluscs, all of which refuse to take plant food, but when starving will permit algae to enter the cells of the gut and thrive. Some of the algae may subsequently be transferred from one generation to the next in the eggs, and the same is true for some flatworms. *Convoluta roscoffensis* picks up algae from the egg-shell when it hatches, the plants multiplying in its tissues during growth. After some time, however, the worm ceases to feed after the fashion of an animal and the gut degenerates, whereupon the algae become a source of food that is gradually depleted. When the plants have been used up the flatworm dies in the colourless condition in which it started life, but by this time the eggs have been laid and the next generation of worms has been endowed with its "heritage" of algae.

Unlike any of the animals mentioned so far, corals harbour zooxanthellae that cannot live independent lives. The animal can in some instances live in the absence of the algae, which, for instance, are thrown out under conditions of darkness, inanition and oxygen deficiency – without deleterious consequences. The only bivalve molluscs that harbour zooxanthellae are the Giant Clams (*Tridacna*), which extract living algae from their food and cultivate them in the phagocytic cells that abound in the blood sinuses on the thick and scalloped edge of the mantle, a region that is generally protruded from the shell and exposed to the full force of tropical sunlight. The mantle's edge is modified to lodge as many algae as possible, and these plants thrive in clusters around lens-like structures that condense light and provide perfect conditions of illumination. A giant clam never loses its digestive organs, but it comes to have a "liver" (hepatopancreas). It ingests algae by phagocytosis and some of the plants are digested for the nutriment they contain, while many reach the mantle and settle down there. They thrive on the phosphatic excretions of the clam and build up organic substances which become available to the animal. The partnership is one of true symbiosis and, as Yonge has shown, this is one of the few instances in which that state really exists.

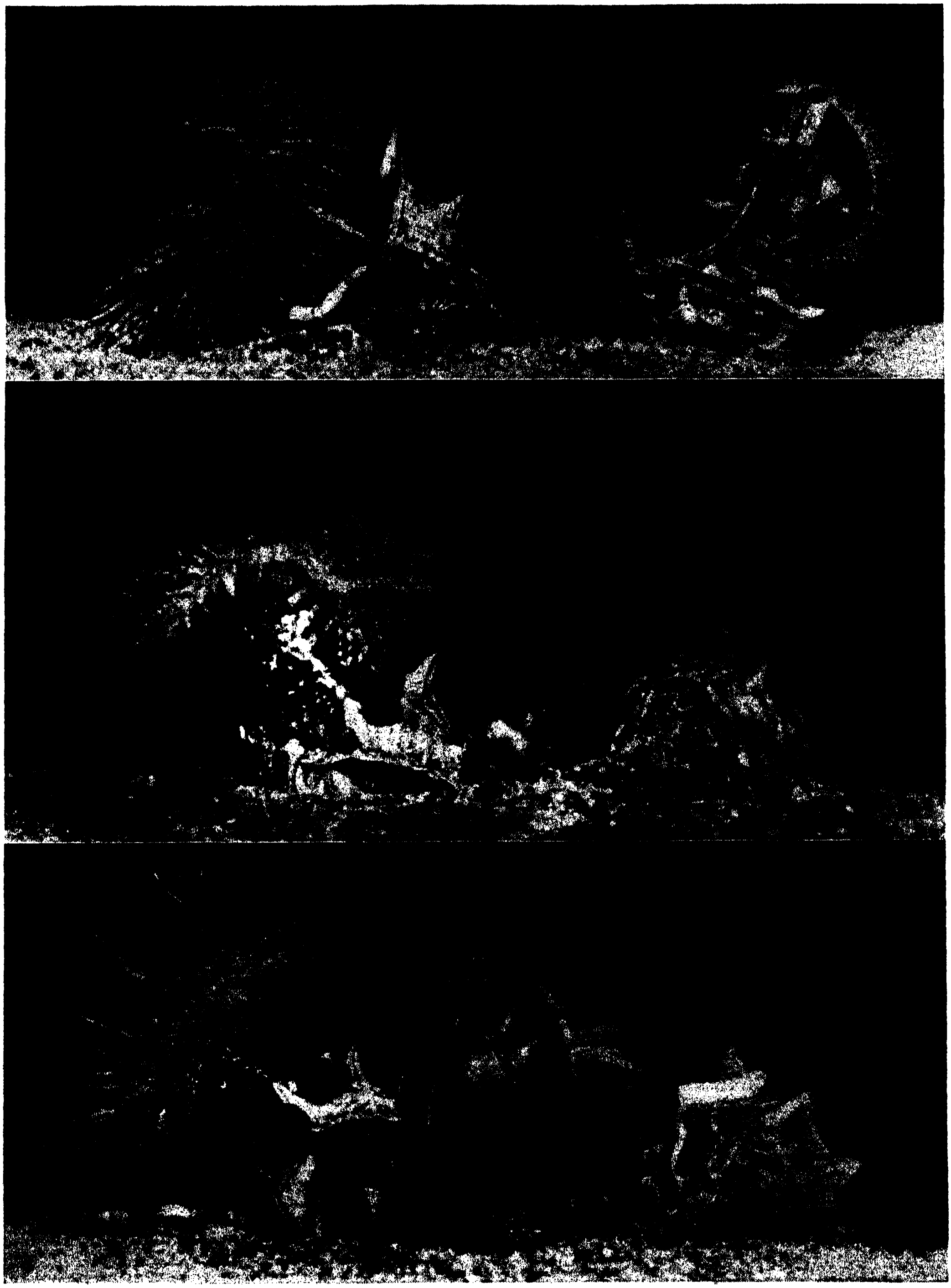
Commensalism. Many animals of the sea-shore live in a commensal association with plants or other animals. The spiny spider crab may be almost completely hidden by attached pieces of seaweed, the hairy hermit crab covers itself with the fig sponge and a third crab, *Melia tessellata*, carries a sea-anemone in each claw and waves them both as it advances. The three crabs respectively gain some degree of camouflage, shelter and protection. A closer commensal relationship exists between the sea mussel and a small gastropod (*Odostomia rissoides*) that lives on its byssal threads. Instead of the usual feeding organ, a radula, the smaller mollusc has a long sucking tube and it inserts this between the gaping valves of the mussel's shell in order to obtain food that rightly belongs to the bivalve. Lastly, the pea crab lives as an inquiline inside the mantle cavity of the mussel, sitting between the lamallae of the gills, clawing the mucus cord and its cargo of finely particulate food and transferring this to its own mouth.

To the sea-anemone, with its radial symmetry, a movement upwards is related to the search for food, downwards means rest or retreat.

More than two animals may live together as commensals. The large hermit crab shelters in the dogwinkle's shell when young, transferring itself to the whelk's shell when fully grown. A feltwork of the hydroid *Hydractinia* sometimes covers the shell, which may bear on its outer surface the large anemone *Calliactis parasitica* and may contain in its uppermost whorl the small ragworm *Nereis furcata*. The hydroid and the sea-anemone serve the crab by helping to keep predators at bay, and they are rewarded for the services by the scraps of food dispersed



These six pictures illustrate a common example of commensalism, and show that the animal associations are not just accidental. A. On the left an empty shell: on the right a shell inhabited by a hermit crab, with two anemones seated on it. B. The hermit crab has removed itself to a fresh shell leaving the two anemones behind. C. One of the anemones has followed and seated itself on the new home of the hermit crab.



A. The second anemone prepares to move to the new home. B. The second anemone, with tentacles withdrawn, is crossing from the old shell to the new. C. The former association of a hermit crab and two anemones is now fully restored, only the shell is different.

by the crab, but what the worm achieves is problematical!

Vertebrate animals may associate with invertebrates—the fish *Fierasfer* habitually living inside the cloaca of a sea-cucumber—or with one another. On land starlings often follow sheep for the sake of the ticks they can find to eat in the fleece, and the related ox-pecker performs the same service for cattle, camels and the rhinoceros. Most remarkable of all is the crocodile bird, which removes leeches and fragments of food from the lining of the mouth cavity and the teeth of the crocodile. In these instances the association has mutual advantages, but it is not close enough to warrant the term symbiosis and hardly constitutes "feeding at the same table" so that perhaps the term mutualism best expresses the relationship. But it is clear that attempts to resolve all the complex patterns of what we have called simple behaviour under two or three broad headings do some injustice to the resourcefulness of many animals that lead unusual lives.

FORM IN ANIMALS

by

DR. BEN DAWES

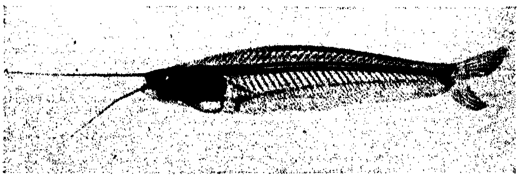
It is remarkable that there are far more phyla than there are types of symmetry (i.e. ways of arranging corresponding organs and parts according to certain geometrical patterns). The most perfect type of symmetry is the spherical, for in a sphere the parts are arranged concentrically about a central point, and an infinite number of axes having similar terminations can pass through this point. This degree of perfection in regard to symmetry is never attained by animals, though it is closely approached by some Heliozoa and Radiolaria.

All animals are influenced by external forces of various kinds—some by the viscosity and surface tensions of watery media in which they live, by forces of cohesion, pressure and such-like—and they are structurally modified by them. Their shapes are to some extent attributable to the shapes of their internal parts, and these are influenced by like forces. Even the form of a crystal is determined by forces, some molecular and others operating from outside, and the rounded form of a droplet of protoplasm is produced not by vital contractility, as was once supposed, but as a result of surface tension, or the law of minimal surfaces. Cells are moulded by the forces that act on them into the spherical or angular shapes they assume in tissues, and the metazoan body as a whole is indirectly affected by molecular forces but less modified by them than is a protozoon.

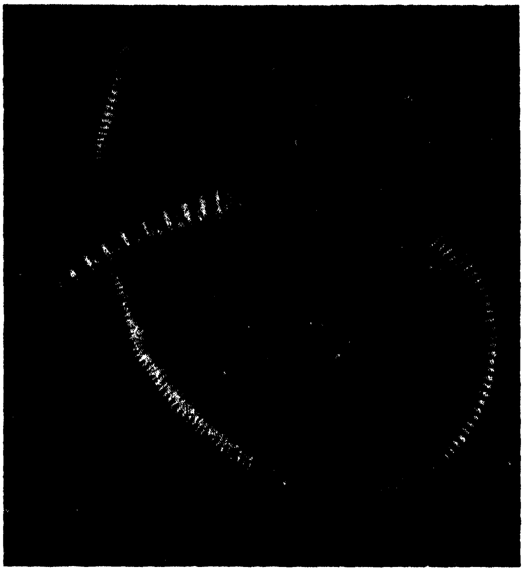
In many worm-like animals the body is divided by vertical partitions (septa) into a unilateral series of compartments, metameres or segments, each containing appropriate parts of various organs or systems of organs, these being indicated externally by a distinct ring or annulus. The arrangement of metameres along the main axis of the body (metameric segmentation) is not confined to worms, of course, but is characteristic of many other invertebrates, and it is seen in a modified condition in vertebrates. The muscles and bones in the trunk and tail of a fish are metameric structures of an obvious kind, but elsewhere in the body of fishes and in other vertebrates metamerism may be partially or completely obliterated by peculiarities of growth. Segmentation is particularly evident in the ringed worms, however, and one advantage these animals have gained from the arrangement is the organisation of muscles of the body in such a way that contractions spread from one segment to the next, thus giving rise to ripples of movement passing along the main axis of the body. Worm-like animals generally have a type of progression that depends on successive series of contractions of this kind, which are seen also in the movements of the intestines of many animals and then get the name peristalsis. This process is responsible for the passage of food substances along the gut, which may or may not exhibit signs of metamerism.

The ancestral metazoan animal probably had a series of closely similar segments, but in all existing Metazoa the end of the body that goes foremost when the animal moves is enlarged and modified, the segments often merging with one another. This "head" region of most worms bears tentacles, palps, gills or other organs, but in some instances it is so simple as hardly to deserve the name head. On the other hand, there are many examples of extreme cephalisation, and in most animals the head has become the most useful region of the body. It is on or near the head that we find the mouth and special organs for capturing food, and here also are the receptors for vision, sound, taste and smell, as well as the main centre of nervous co-ordination, or brain. The head generally goes foremost, even when the animal is retreating, and it usually has better protective structures than the rest of the body. It is perhaps the most important region of the body; certainly, a beheaded animal is a very useless thing indeed.

The multiplication of segments by metamerism readily produces the cylindrical body of a worm which, when pointed at the ends, has an ideal shape for burrowing through sand or soil, although this shape does not suit the requirements of many other animals. Form in animal structure may be modified by the enlargement of some segments and the reduction of others, and also by the development of new structural derivatives of old segments. It is the correlative of the unequal growth of parts, and it generally bears some relationship to the mode of life. Fishes and some other animals are streamlined so that they can move rapidly through a viscous watery medium with a minimal amount of friction. Land animals are less obviously modified in this way, partly because air is less viscous than water, but also because limbs are necessary for running on the ground. But running animals and many birds nevertheless make excellent use of the streamlining principle to render their modes of movement easier and more efficacious. Metazoan animals that move over the ground or some other substratum head foremost generally keep one side of the body towards it. The animal's freedom to move in this characteristic way has resulted in the modification of the metamerically segmented body, so that it has not only front and hind ends, but also upper and lower surfaces, and right and left sides. This bilateral symmetry—in which the right side of the body approximately corresponds to the mirror image of the left—is presumed to have arisen in the early ancestors of Metazoa which adopted a life on the bottom of the sea and had before them several alternatives. They could learn to walk on the sea floor, lie quiescent or attach themselves to it, burrow in it, or rise up from it to swim in the water above them.

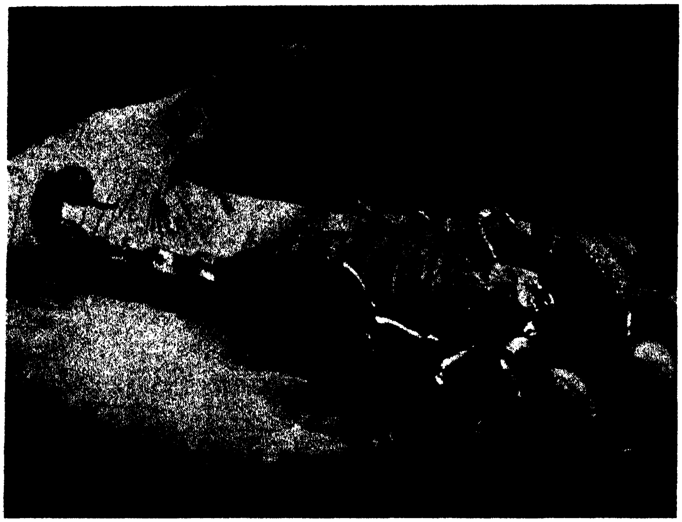


The transparent body of the Ghost-like Catfish reveals a segmentation common to all vertebrates but seldom seen as clearly as it is here.



The earthworm shows that segmentation of the body must have been one of the early causes leading to specialisation such as we see in the higher invertebrates and in the vertebrates.

Movement in free-living Metazoa seems to have promoted bilateral symmetry, and sessile life favoured an entirely different type of symmetry. Hydra-like coelenterates often live attached to some substratum in such a way that they are orientated from above downwards. Up is the way towards food, and down is the direction in which there is comparative security. The body need not have right and left sides; indeed, it is



The Imperial Scorpion, *Pandinus imperator*, exhibits the metameric segmentation except at the front end where a modification in structure has obscured it.

advantageous if instead its parts are arranged like the spokes around the hub of a wheel or the ribs around the handle of an open umbrella. This type of symmetry is radial, and it is characteristic of coelenterates, even types such as the jellyfishes that adopted a drifting mode of life. Sea-urchins, starfishes and other echinoderms also show radial symmetry, and during their early history they probably had habits similar to those of the coelenterates. The sea-lilies (crinoids) of the present day mostly live attached to rocks or other components of the sea floor, and they have some of the characteristics of the hydroid coelenterates. Other echinoderms cut their moorings at some period during their history, as the feather-star regularly does during its development—by snapping the stalk that formerly anchored it to stones or seaweeds. The sea-cucumbers redeveloped bilateral symmetry and used this with great advantage to their mode of life in cracks, crevices or burrows.

The vast majority of animals kept to the bilateral architectural plan characteristic of flatworms, roundworms, ringed worms, jointed-limbed animals and all vertebrates. Mussels and some other shell-fish also display bilaterality, but many other molluscs have largely lost it. Snails and their near relatives have a bilaterally symmetrical head, but unequal growth of the two sides of the body, coupled with torsion, soon obliterates all signs of symmetry behind the head during development. Like the hermit crab and a few other invertebrates, gastropod molluscs display asymmetry. Further, the internal organs of many bilaterally symmetrical animals are generally disposed asymmetrically, for they have to be accommodated in what small space is available inside the body, so that a long intestine sprawls across the body cavity in numerous loops and folds. Even the external symmetry is imperfect in such animals, the two sides of the body making a fair but not a perfect match. If the right and left sides of the human face had equally attractive features, film stars would not mind from which side they are photographed in profile. Perfect symmetry is hypothetical, like the average man of common parlance.

CRABS AND THEIR METHODS OF DEFENCE

by

DR. JOHN P. HARDING

Crabs as a whole provide a number of paradoxes. Heavily armed and armoured, they are adepts at camouflage. Formidable in appearance they readily seek refuge when disturbed. Primarily scavengers, feeding on dead animals or vegetable matter, they will feed on other animals, even, in many cases, being guilty of cannibalism, feeding on members of their own species. Preying on other animals they are themselves the prey of many. There are exceptions to all of these, of course.

Of all these characteristics, it is perhaps the art of camouflage which catches the attention most. This is of two kinds: that in which the shape of the body and natural coloration form a means of harmonising with the surroundings; and that depending on the crab's own ability to add to these initial advantages, as when the spider crab decorates itself with seaweeds, sponges, hydroids and the like (see also pp. 234–235).

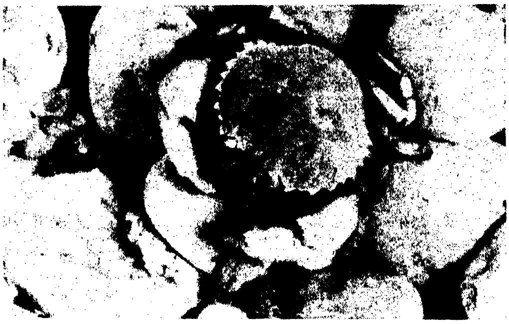
The examples that follow are all taken from European species, but their application is general for the crabs of the world. Indeed, there are even more striking examples among the crabs of the tropics, but pictures of these are rare.

The enemies of crabs include fishes, such as conger, wrasse and cod; certain sea-anemones and octopus; gulls and other sea-birds, and, at low tide, rats which invade the shore, especially at night. Larger species of crab prey on smaller forms. Crabs must, therefore, hide or succumb.

A portion of the carapace of *Maia squinado* to show the bits of seaweed, etc., which have been fitted on to special hooked bristles by the crab itself.

A further provision having a marked survival value is that which enables a crab to cast off a claw or a leg, either when such a member is seized by an enemy or after it has been damaged by a shifting lump of rock. Each limb has a special breaking plane close to the body which enables this to be done without loss of blood, and it is not uncommon to find a crab with several limbs missing and in the process of regrowing them, the new ones appearing as buds of soft flesh on the basal joints of the lost limbs. One even had all but two legs missing, with one left on each side of the body, and one claw, yet was apparently still able to find a living.

Spider Crab (*Hyas*) which decorates only it claws but produces nevertheless, an efficient disguise.



The Circular Crab normally rests with its claws and limbs drawn in, when it looks like a whitish pebble.

The Fluted Crab (left centre) harmonises well with stones.

This Spider Crab, *Macropodia longirostris*, starts with the natural advantage of having long slender legs so that it is difficult to detect when resting among seaweed without additional aids.

Ebalia tuberosa, living at a depth of 10 to 20 fathoms, bears a strong resemblance to the pebbles when at rest.

CHAPTER XV

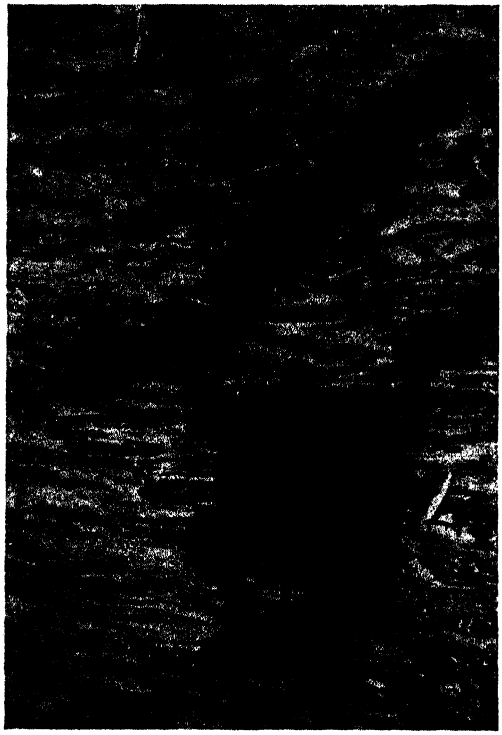
THE CLASSES PROTRACHEATA *(PERIPATUS)* AND THE MYRIAPODA

PERIPATUS: A ZOOLOGICAL CURIOSITY

by

DR. S. M. MANTON, F.R.S.

IF, in a damp forest of the Southern Hemisphere, in South Africa, Australia or South America, you should chance to grub about among decaying wood lying on the ground, under stones or under the bark of fallen trees, in fact, in the kind of places frequented by woodlice in this country, you might stumble upon one of the most extraordinary animals living to-day. The first introduction may be one or two jets, or a spray, of a milky-white fluid shot out from a crevice for a distance of three to twelve inches, which solidifies instantly into sticky white threads that adhere most tenaciously to the fingers. Then you know you have found Peripatus, an animal which forms a link, that would otherwise be missing, between the soft-bodied Annelid worms, and the hard-skinned Arthropods—insects, spiders and centipedes. A zoological curiosity which appears to have persisted, with remarkably little change, for countless millions of years. The structure and mode of life of Peripatus offer a mixture of primitive and advanced characters.



A group of Peripatus, including adults and young.

Opening up the crevice from which the sticky threads were ejected reveals a small animal, looking like a velvety slug, one to three inches long, with a sinuous, tapering body, rather contractile, bearing on its head a pair of flexible antennae, very like a slug's "horns". But whereas the slug's eyes are at the tips, the beady eyes of Peripatus are at the bases of the antennae. Another feature distinguishing it from a slug is the possession of some twenty pairs of short, baggy legs, each ending in a pair of hooks, and the skin, in spite of the creature's slimy greeting, is dry, and soft and velvety to the touch. Its colour is variable, often matching exactly the surroundings, and each species may range from a dark slate to a reddish brown or a terrac-otta, with generally a darker stripe down the back. Reddish-brown specimens on the fallen stinkwood trees of the Knysna Forest, for example, are remarkably difficult to see, the colour being precisely that of the wood, but in the caves on Table Mountain is a species completely lacking pigment, in the manner characteristic of so many cave-dwelling animals.

The sticky threads come from two little knobs, the oral papillae, placed underneath the head, on either side of the mouth, and carrying the openings of the slime glands, the slime being stored in a reservoir, rather like the sac of a fountain-pen, on each side of the body. While in the body it is fluid, but on contact with air the surface immediately solidifies, so that adhesive beaded threads can be drawn out and used as a defence against enemies. But although Peripatus is carnivorous and small animals are easily entangled in the threads, it has never been seen to eat those bound in this way.

In captivity the animals are not always easy to feed. Some will take live termites, woodlice and small insects. Others will greedily eat freshly-killed crickets and grasshoppers. Raw sheep's liver is very generally accepted, but some individuals will starve rather than feed in captivity. Individuals of two species have been kept alive in this country for four years, and young ones born in captivity have grown and thrived for two years—before going on hunger strike!

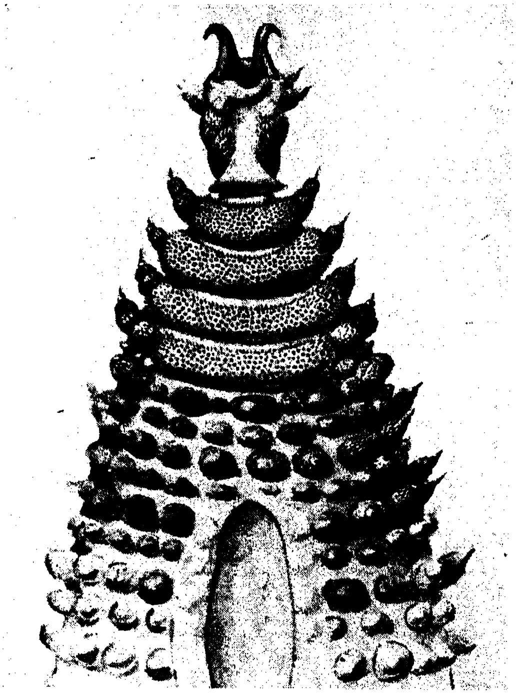
The eyes are curiously limited in power, for the animal cannot see ahead, only upwards and outwards, and they are so simple as to be incapable of recording more than variations in brightness of light. There is, however, an elaborate system of sensory hairs, organs of touch and taste, clothing the antennae and most of the body. The animal is also sensitive to dampness, a thing of vital importance.

All terrestrial animals must evolve some mechanism to avoid being dried up. The pores in the human skin, for example, are automatically regulated to prevent undue evaporation. Peripatus has failed in this, and must, as a result, keep to damp situations. In an ordinarily dry room it will lose a third of its weight in less than four hours. It dries up twice as rapidly as an earthworm, and forty times as rapidly as a smooth-skinned caterpillar of the same size. This is surprising, since the earthworm is lower in the evolutionary scale and has a wet skin more permeable to water than the dry cuticle of Peripatus, which will not wet. The explanation lies not in the skin, but in the method of breathing. Peripatus, like so many terrestrial Arthropods, breathes by tracheae, breathing-tubes which conduct the air from openings on the surface of the body to the inner tissues. But whereas terrestrial insects avoid loss of water by having a much-branched tracheal system,

Peripatus moseleyi, from South Africa, showing the animal contracted and starting to walk, the first nine pairs of legs only being in action. The worm-like contraction and extension of the body indicates an absence of the rigid cuticle which is characteristic of Arthropods as a whole.

with few openings and an efficient mechanism for closing them, in Peripatus the tracheae are simple unbranched tubes. Consequently, an enormous number is required, each with its separate opening; and since there is no mechanism for closing them, Peripatus must keep in a continuously damp place if it is not to dry up and die in a few hours. It is therefore peculiarly the prey of circumstances, with a result of considerable interest to the student of evolution. A colony of Peripatus in one damp locality will be quite isolated from another if the country between is dry, and in course of time each area has evolved its own species, just as oceanic islands tend to evolve their own endemic species. And if such an area should be temporarily flooded, all the Peripatus will be drowned; and years afterwards, although the environment, restored to normal, will still be as suitable as it was before, not a specimen will be found, for none will have been able to get across the intervening drier country to repopulate it. But in spite of the repeated isolation of small colonies and the consequent evolution of a large number of species, the differences between one species and another are small.

It is, perhaps, in reproduction that Peripatus shows the greatest contrast between the simple and the elaborate. Fertilization, for example, is marked by a most careful coition, coupled with a remarkable sequence leading up to the fertilization of the eggs. And in many species there are features which parallel the highly-evolved embryonic development of mammals. In some species the male deposits the spermatozoa in capsules anywhere on the surface of the female's body, even on the legs. A lack of discrimination appears to exist, since a male will sometimes deposit the capsules on another male. Soon after the spermatophores are deposited, white blood corpuscles invade and break through the skin beneath them. The cuticle of the body and lower wall of the spermatophore are ruptured and the spermatozoa swim into the blood and work their way to the ovary, forcing their way through its walls in large numbers. The young egg-cells use the sperms as food and grow for a year on this nourishment before they are ready for fertilization.

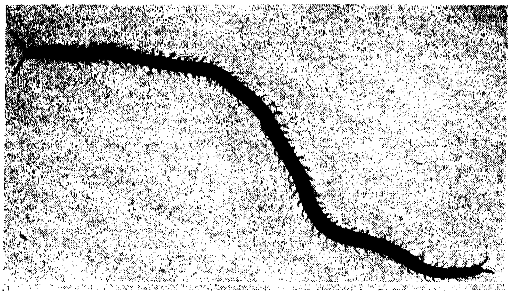


A detailed drawing of the leg of Peripatus showing the terminal claws and the small spines on which the animal walks. Papillae, such as are seen here on the leg, cover the whole surface of the body.

In most species the young are born alive, although one Australian species lays large, yolky eggs. Development takes place in the uterus, and the embryo absorbs nourishment from the parent through its walls.

In one South American species a placenta, analogous to that of mammals, has been evolved. Pregnancy in many species lasts for thirteen months and, as young are born every year, there is one month in every year after the female reaches maturity, in her second year, during which she is carrying two sets of embryos, one in the early stages and the other near term.

Descended from aquatic ancestors, Peripatus has solved the problem of living on dry land by acquiring suitable means of getting about, efficient feeding devices and sense-organs. It has dispensed with aquatic larvae. But although it has become thoroughly terrestrial, acquiring a dry skin like all terrestrial animals, it has developed a tracheal system which ties it inevitably to a damp environment, making further



The centipede *Geophilus subterraneus* lives in the soil, a fast-moving animal preying upon small worms, insects and the like. Whether a particular species of millipede or centipede is harmful or not to the garden can be determined by the speed at which it moves. Quick-moving carnivores, like *Geophilus*, may be labelled as beneficial since they destroy small vermin; the slowly-moving forms are vegetarian and likely to damage roots.

conquest of the land impossible. So Peripatus, having long ago forsaken water for land, has nevertheless marked time through countless years.

Relatives of Peripatus

Peripatus is not the only obscure and puzzling member of the Arthropoda. The class Myriapoda, the next to be considered, is nothing more than a motley collection of primitive arthropods, unfamiliar, obscure, and having little real relationship one with the other. In other words, the Myriapoda forms a convenient taxonomic receptacle into which we can place a number of animals otherwise extremely difficult to classify. To begin with, we speak of the millipedes and centipedes as if they were almost one and the same thing, yet in spite of superficial resemblances they have few things in common.

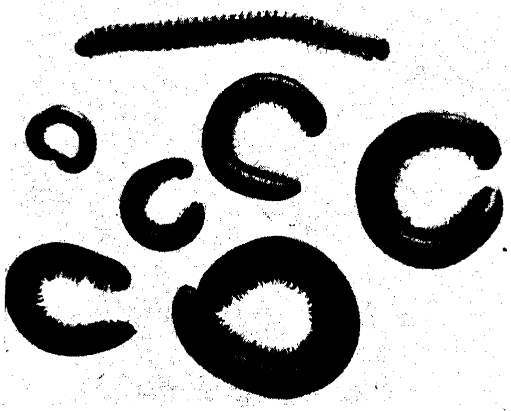
The centipedes are quick-moving, carnivorous, solitary; with body flattened, a pair of legs to each segment and poison glands working through the jaws (that is, they are offensive in character); in addition, there are many details of internal structure which mark the centipedes clearly from the millipedes. The millipedes, on the other hand, are slow-moving, vegetarian, gregarious (which is perhaps a general feature of vegetable-eating animals rather than a peculiarity of any one group); with body rounded and a defensive poison exuded from glands placed at intervals along the sides of the body. Therefore, although the millipedes and centipedes resemble each other so closely that most people fail to tell one from the other, and although they both belong to the phylum Arthropoda, they are, in fact, not closely related and such superficial resemblances as they have are more the result of a convergent evolution.

Other animals usually included in the Myriapoda are the Pauropoda, Symphyla and others, all minute, less than one-twentieth of an inch long, most of them somewhat centipede-like in appearance, normally living under stones, logs or moist leaves, and usually quite unknown even to the average naturalist. Despite this, they are important. For example, certain of the Symphyla, vegetarian in habit, are proving to be pests on hothouse plants, especially in the United States. On the other hand, the less harmful of the Pauropoda and Symphyla must be reckoned, with the millipedes, woodlice and a host of other smaller forms of life, as natural scavengers, composting the dead remains of plant and animal, thereby achieving the cleansing of the soil and the maintenance of its fertility.

A few of these obscure Myriapoda, particularly those known as the Tongue-worms, have taken to a parasitic mode of life. They are minute and worm-like, having lost their legs, and occur in dogs and other animals, and in human beings that eat raw flesh. They are picked up by the host animal in the form of eggs, from which six-legged larvae hatch. Later the legs are lost, the parasites—now tongue-shaped—hanging by hooks on their heads to the lining of the lungs. In time, eggs are laid, which are sneezed out by the host, to be picked up and infect other animals.

Class Myriapoda

This class includes the Centipedes and Millipedes, numbering several thousands of species distributed in hot and cold climates throughout the world. All are terrestrial, although a few live between tide-marks. Their bodies consist of a series of segments, similar in appearance except for the first, which is clearly distinguishable as a head bearing a pair of antennae and, underneath, the mouth parts consisting of a pair of jaws and one or more pairs of maxillae. Each segment behind the head bears one pair of legs in centipedes, and each after the fourth segment bears two pairs of legs in millipedes. Other differences between the two groups are: centipedes have a flattened body, a pair of poison fangs, and are active predatory carnivores; millipedes have a rounded body, no poison fangs and are slow-moving vegetarians.

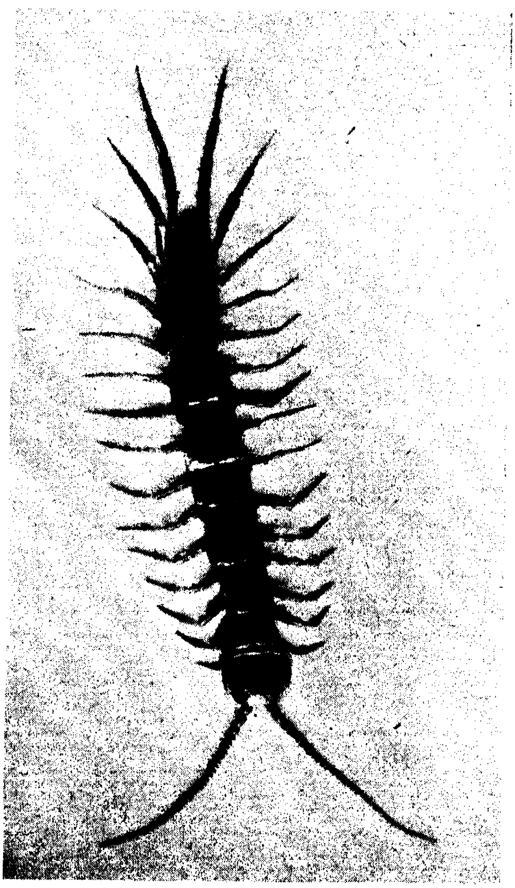


The Snake Millipede *(Julus terrestris)* at various ages and in various altitudes. It is a vegetarian, often harmful to garden crops, and is a slow-moving animal.

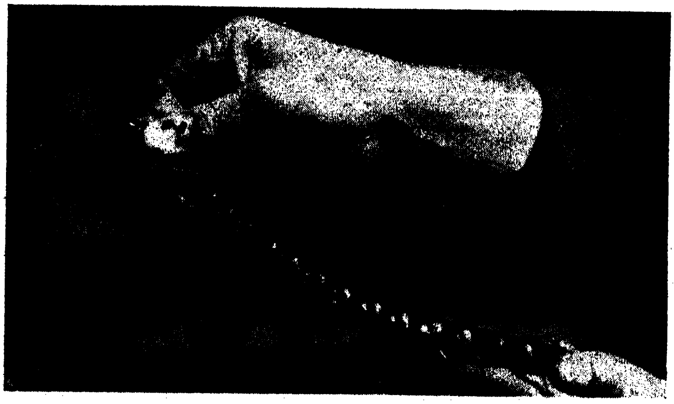
Order Chilopoda

Centipedes are usually pale brown or black, rarely brightly coloured, very occasionally, as in *Geophilus electricus*, luminescent. The typical habitat is under dead leaves, stones, rotting vegetation or in rotten wood. The food consists of insects or their larvae, or earthworms. In some of the larger the bite is dangerous to man. The predatory habits are even extended to members of their own species.

The breeding habits of the European *Lithobius forficatus* have been studied in detail. The eggs are extruded singly from an opening on the last segment and each as it emerges is caught on a pair of hooks on the undersurface of the segment. Should the male see it he will rush at



The Centipede *(Lithobius forficatus)* has only 30 legs, not a hundred as the name would suggest.



The Giant Centipede *(Scolopendra gigas)* of Trinidad.

the female, seize the egg and devour it. Therefore the female does her best to move off, hastily coats the egg with a sticky fluid and rolls it over and over until it is camouflaged with grains of soil and hidden from the sight of the male. The young Centipede when first hatched has only six pairs of legs. As it grows fresh segments make their appearance in front of the last segment.

Not all Centipedes have the number of legs suggested by their name. Some species are short and squat, others have more than a hundred pair of legs. The house centipede of North America has 15 pairs of legs, but all are long, the hinder pairs longer than the body itself, so that the creature looks rather like a many-legged spider.

Order Diplopoda

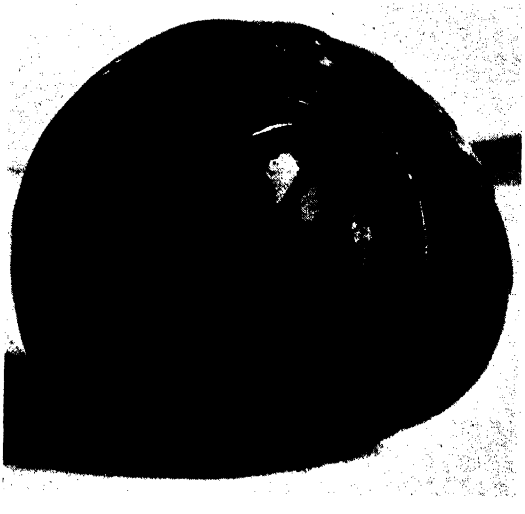
The Millipedes feed not only on decaying vegetation but also on roots and tubers. They can, therefore, constitute a pest to crops, as for example the wire-worm, *Julus terrestris*.

In the absence of poison fangs Millipedes have for defence the ability to exude an unpleasant odour from "stink-glands".

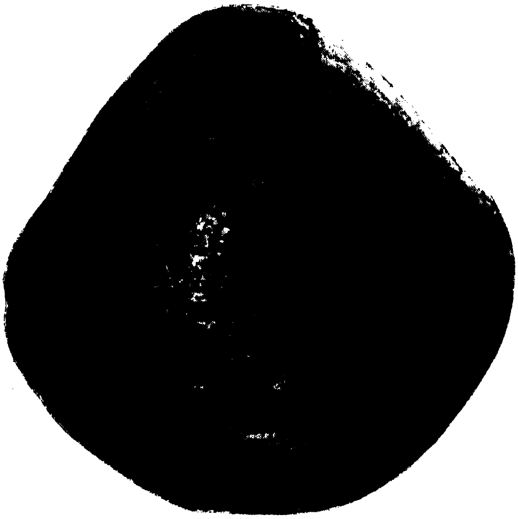
The nesting habits of *Julus terrestris* show a high degree of parental care. The female retires just beneath the surface of the earth and mixes a cement, using the earth moistened with her own saliva to construct a dome-shaped nest with a hole at the apex. Through the hole she lays her eggs in the nest, and finally seals the opening with a dab of the "mortar". Then she leaves it.

The young millipedes are hatched with three pairs of legs only.

SIMILARITY IN HABIT IN TWO WIDELY DIVERSE ANIMALS



A millipede, the South African Pill *(Sphaerotherium obtusum)*, rolled up as a defensive measure.



The Armadillo *(Tolypeutes tricinctus)*, a mammal, rolled up.

The Woodlouse *(Armadillium vulgare)*, a crustacean, rolled up.

CHAPTER XVI

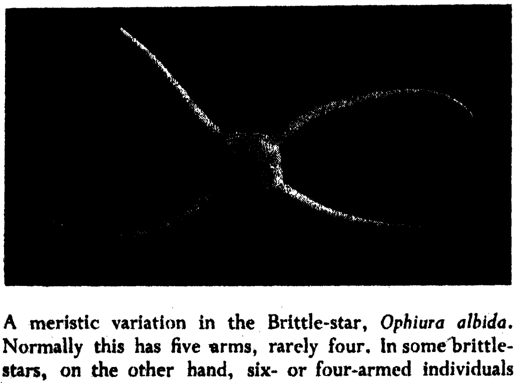
INTRODUCING THE INSECTS

With some preliminary remarks on variations in form, the natural balance and ratio of multiplication in animals

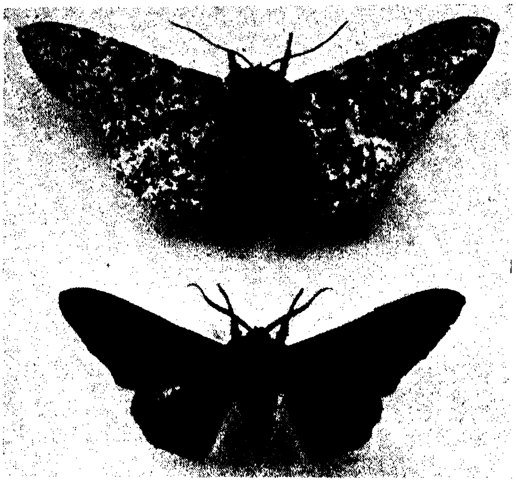
Variations in form

IT is obvious, even to the least observant, that no two individuals of a species are completely alike. This holds true whether we are dealing with men, snails, sponges or Amoebae. The study of these variations is one of considerable importance. The first task of the biologist is to seek to determine what kinds of variations occur in nature, which are due to environmental influences and which are inheritable. Environmental variations may be due to differences in feeding, variations in habits, differences in the breeding seasons as well as to changes in the physical nature of the environment. Thus there may be a gross variation in size due to an excess or deficiency in food or some trace element. There may be variations in structure, as in the degree of spininess of the shell of certain molluscs, or in colour, as in shells of some molluscs or the bodies of certain insects, according to the type of food eaten. One physical influence may be mentioned: the tendency to a darker colour in animals—slugs, insects, birds and mammals—living in damp places.

Sexual dimorphism in the Pea Crab *(Pinnotheres pisum)*. The male is markedly smaller than the female.

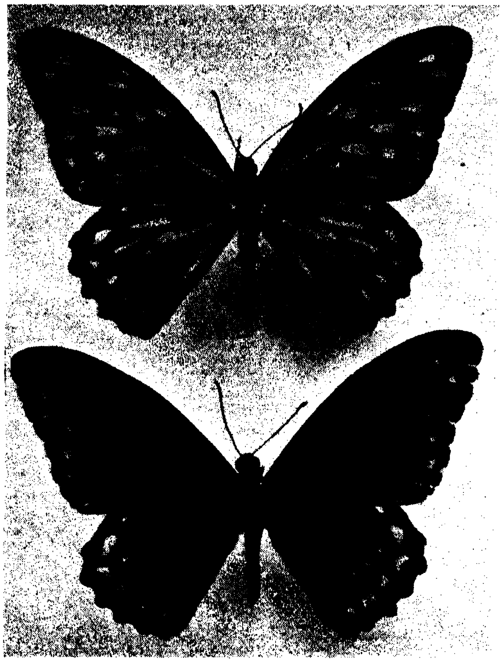


A meristic variation in the Brittle-star, *Ophiura albida*. Normally this has five arms, rarely four. In some brittle-stars, on the other hand, six- or four-armed individuals are common.

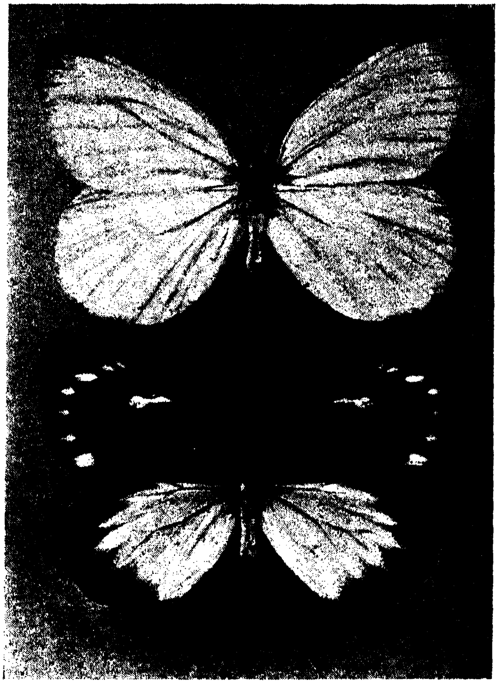


The moth *Amphydasis betularia*: above, the typical form; below, the melanistic variety.

This tendency to vary, coupled with the struggle against living enemies and against adverse physical conditions, together with the high rate of propagation of most animals, is one of the more important aspects of the study of Zoology. Variations under the pressure of natural selection, whereby those individuals less well fitted

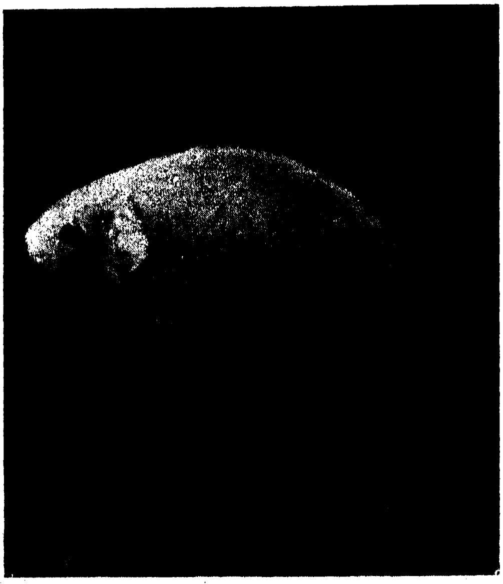


Variation with the season, or Seasonal Dimorphism. Above: *Papilio clytia* var. *dissimilis* found in a dry season. Below: *Papilio clytia* var. *panope* found in a wet season.



Variation with sex, or Sexual Dimorphism. The butterfly *Delias descombesi*, of Assam: the top specimen is a male, the lower specimen a female.

The Whitetailed Goldfish on the right and the Telescope-eyed Goldfish, two of the many artificial varieties produced by artificial selection.



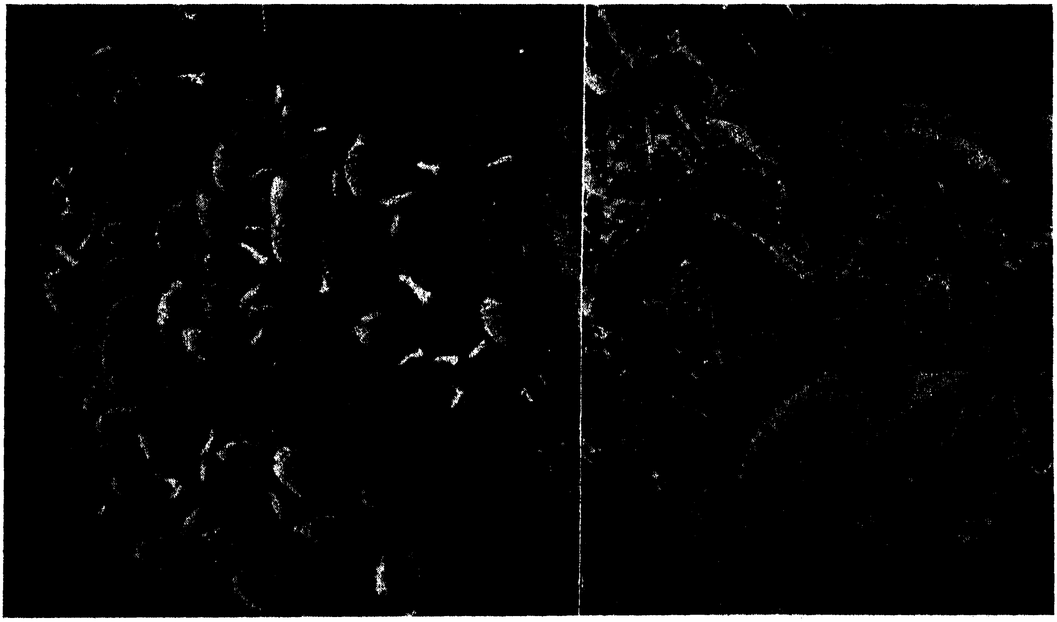
in the struggle for life are eliminated, underlie the whole story of organic evolution.

Aphides and their enemies

The picture drawn by Dr. Crile (see Chapter 5) of the incessant struggle between living things, vivid and impressive though it be, is but an introduction to one of the most interesting aspects of the behaviour of living animals. Like every other aspect, however, it could not be dealt with exhaustively if every page in this book were devoted exclusively to it. There is, nevertheless, one constituent of this struggle which is of vital importance; namely, the very old, yet ever fresh, story of the balance that is maintained during the course of it. In spite of the relentless struggle, there is a natural balance which is very difficult to upset, except by a natural catastrophe or the catastrophic effect of man's interference. However great may be the inroads made by an enemy, the ranks of the victims are capable of being re-formed and the species continues, fluctuating perhaps in numbers, but remaining more or less constant over a period of years. There can be no better illustration of this than is provided by the story of the plant-lice, or aphides, and the host of their predators, a story in which a high rate of fecundity balances the high rate of mortality. In examining this one example we shall see a number of subsidiary events and adjustments typical of the world of living things. In other words, in the story of the aphides and their enemies we have a cameo indicating the composition of the large picture.

A convenient starting point for the story is the late autumn when the female aphides lay their eggs in the crevices of bark and other such places. These eggs are protected by thick shells and are the main link between the population of one year and those of the succeeding year. Most of the adults, females or males, die off and it is doubtful whether any of them survive to the following year. The females lay only one egg each.

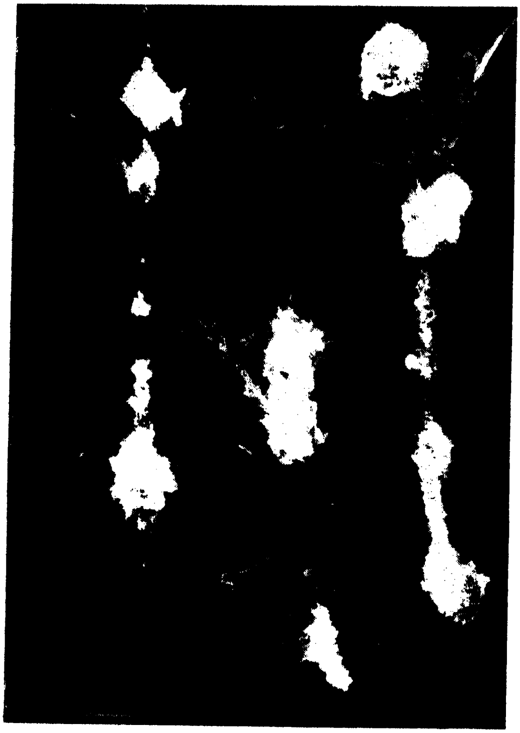
In the spring, the eggs hatch, but only females emerge, most of them being wingless. The winged forms, naturally, are able to move about and found fresh colonies. During the spring and summer, these females reproduce parthenogenetically. That is, without the intervention of males young are born, alive and fully formed, though much smaller than the adults. The rate at which this vivipary (see p. 216) proceeds accounts for the swarms of aphides which appear almost overnight in the spring. A single female may produce young at the rate of one every half-hour under the best conditions, and these youngsters begin feeding soon after birth. They grow quickly, moulting their skins at each stage of



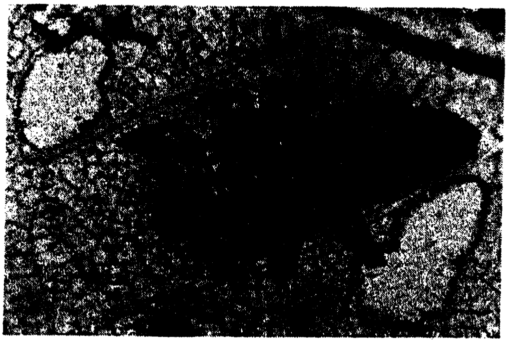
On the left, Greenfly, or Aphides, congregated on a leaf. Here are fully-grown, immature and newly-born individuals. The dried and shrivelled skins resulting from their moulting are scattered among them. On the right, another group of Aphides more highly magnified. The alternative name of Plant-lice is understandable.

growth, and within a few hours reach maturity and themselves start breeding. In twenty-four hours, then, each female would become the grandmother of several hundreds. It is the parthogenetic reproduction, with every member of the summer population a functional female, which, combined with the rapid proliferation of the embryos, accounts for the swarms of aphides. Unchecked, they would destroy all vegetation on the earth in a short while. Fortunately, several natural checks are present, and the more rapid the increase in the aphides the more do their enemies fatten and grow; the fewer the aphides the less the increase among the enemies. Thus although there may be temporary plagues, these are soon brought within bounds and, what is more important, the natural balance between prey and predator is such that those insects that control the aphid populations are never in danger of themselves becoming a pest.

Greenfly swarming on a rosebud. With such a swarm of plant-lice, each with its beak buried in the plant tissues and greedily sucking the sap, it is not surprising that the bud tends to wilt.

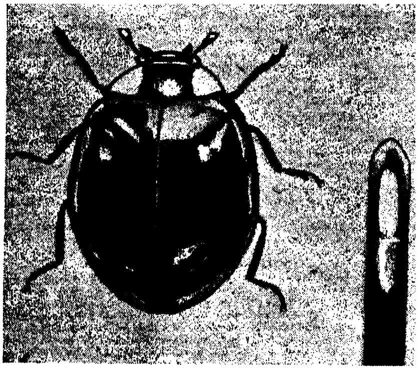


The Woolly Aphis or American Blight. The only signs of this pest are the patches of white woolly material on apple trees, beneath which the insects live and suck the sap.



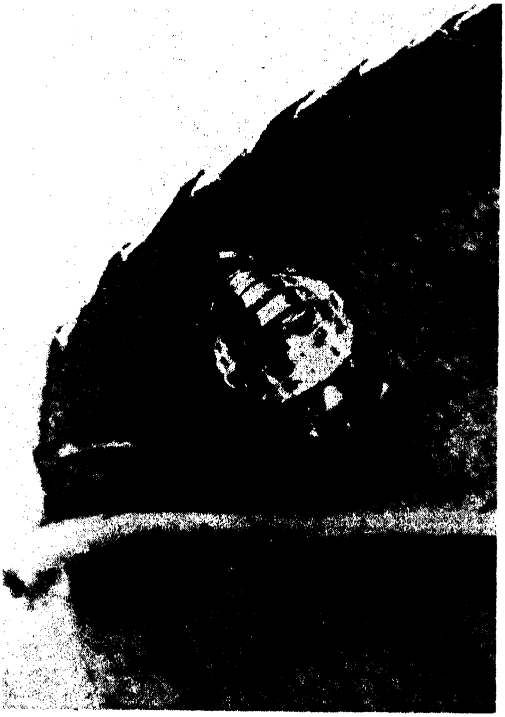
The rapacious larva of the Ladybird which feeds on aphides.

The first and most numerous of the aphid controls is provided by the ladybird beetles, which at all stages feed on aphides and such insects. Their eggs are laid on the leaves of plants and the larvae, black with yellow spots, roam the foliage in search of their natural food. Allied with them in the battle are the larvae of the lacewing-flies, resembling somewhat the ladybird larvae in form but greyish in colour. The larvae of the hover-flies, the next enemy of plant-lice, have been described as wandering over the surfaces of the leaves, waving their front end from side to side like an "independent elephant trunk". This they do in searching for their food, and although maggot-like and lacking the legs of the ladybird and lacewing larvae, their destruction of pests is none the less effective. Finally, among the principal insect enemies must be listed the ichneumon flies which parasitize the aphides leaving their empty straw-coloured husks on the leaves.


The gardener's friend, the Two-spotted Ladybird beetle *(Coccinella bipunctata)*; the eye of the needle gives the scale of magnification.

The eggs of the Ladybird laid on the underside of a leaf, among the aphides.

Here then is one small feature in the general struggle wherein a high rate of fecundity is matched against a series of natural enemies. But the position is nowhere as simple as this. Each of those engaged, the plant-lice, the ladybird, the lacewing or the ichneumon is linked with the destiny of other organisms; and so on in an ever-widening series until it may be truly said that the fate of every individual, certainly of every species, has its place in the long and tangled skein of cause and effect which goes to form this thing we refer to as the balance in nature. And no one can pretend to study one


The pupa of the Ladybird.

small section of the field, ignoring the rest, without losing his sense of proportion.

The egg of a hover-fly, the wasp-like helicopter, that is the hereditary enemy of the aphides.

The natural fecundity of the earth

Any student of natural history will fail to get his ideas in perspective unless account is taken also of the teeming myriads of living things existing to-day, and of the truly countless myriads that have lived and died in the past. The mind is overwhelmed in any attempt to visualize what these numbers mean, but at least we may see a tiny corner of the whole picture by listing a few of the known facts.

One thing at least will emerge from the study of these figures: that every year the world of living things presents an enormous quantity of raw material for experimentation, from which nature may select or discard. This must be kept clearly in mind when considering the processes that have contributed to the mechanism of evolution.

To begin with, it is worth while stressing the enormous numbers of species living on the earth to-day. A good idea of what these numbers mean can be gained by the following example. If you were to start now merely reading out the names of the species of living animals known to us, and were to continue to do so without rest night and day, you would not finish for well over a month.

Further than this, however, each species represents countless myriads of individuals. Some estimate of what these countless numbers mean can be best obtained by listing a few examples of the rates of multiplication found among just a few of the species.

Fecundity among lower organisms

Paramoecium (see p. 141) divides by splitting into two. This may happen several times a day, and since the offspring are capable in turn of reproducing within the next 24 hours, it has been calculated that the descendants of a single individual would number more than 3,000 million in the course of a year if there were no check from enemies and no shortage of food.

Fecundity on the shore

On a beach 150 yards deep and two miles long on the south coast of England it has been estimated that there are:

16,000,000	limpets
800,000,000	mussels
5,000,000	winkles.

The numbers would, of course, vary from one beach to another. This is merely one specimen of which a survey was made.

Fecundity in the sea

The number of offspring varies with the species from one a year to 500,000,000. In general terms it may be said that the larger the animal, or the greater the degree of parental care exercised, the less numerous will be the offspring. Some of the outstandingly high figures are:

Asterias rubens, the common Starfish of Europe will lay 2,500,000 eggs at a single spawning.

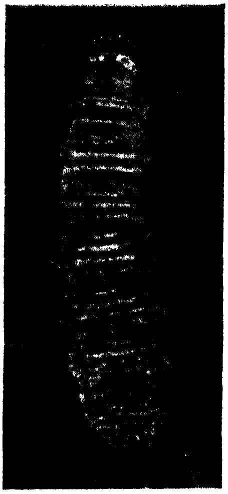
Mytilus edulis, the common Mussel, will lay 25,000,000.

Cancer pagurus, a Crab, lays 3,000,000.

Luidia ciliaris, a Starfish, lays 200,000,000.

Ostrea virginica, the American oyster, lays 500,000,000 in a year.

A Blue whale measures on an average 90 feet long and weighs 100 tons. For ten years up to 1939, 30,000 Blue whales were killed annually, representing 300,000,000 tons of



The larva of the hover-fly.

whale carcase slaughtered in 10 years. Yet the species is still abundant in the Antarctic.

If a single mussel will lay 25,000,000 eggs a year and there are 800,000,000 mussels on a strip of coast a mile long, the total number of eggs laid by all the mussels in the world each year can be better imagined than described.

Fecundity on land

Here are a few figures for land animals:

In an acre of pasture land in England there may be 1,000,000 to 2,000,000 spiders alone.

An acre of the same ground will contain 5,000,000 animals of all kinds living in the soil.

In terms of economics the following may be noted:

Damage to crops by locusts annually in the world, £ 6,000,000.

Crops destroyed by insects and mites is equal to 10 per cent. of the world's harvest.

The names used for young animals and particularly for insects

Considerable confusion is caused by the multiplicity of names applied to the young stages of animals. This is particularly so in dealing with insects. In order to clarify this, therefore, the following definitions and explanations are given for terms used in this book.

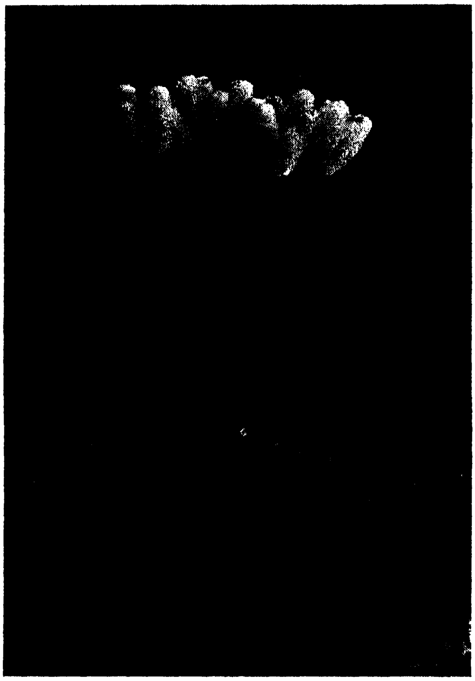
Embryo. That period of development of an organism from the first cleavage of the egg until its emergence from the egg membranes (i.e. until it hatches).

Larva. In lower invertebrates, that stage following the embryonic in which the form of an immature animal differs from the parent, implying a metamorphosis before assuming adult characters.

In insects, the larva is the immature, wingless form hatching from the egg which persists in spite of increase in size and of minor changes until the pupa or chrysalis is formed. Alternative names used for the larvae of different groups of insects are: grub, maggot, caterpillar and, in a special sense, nymph.

Nymph. The immature stages of those insects with an incomplete metamorphosis, and the immature stages of Arachnida. Sometimes used in a restricted sense for the stage between the last two moults; that is the stage corresponding in insects with a complete metamorphosis to the pupa or chrysalis.

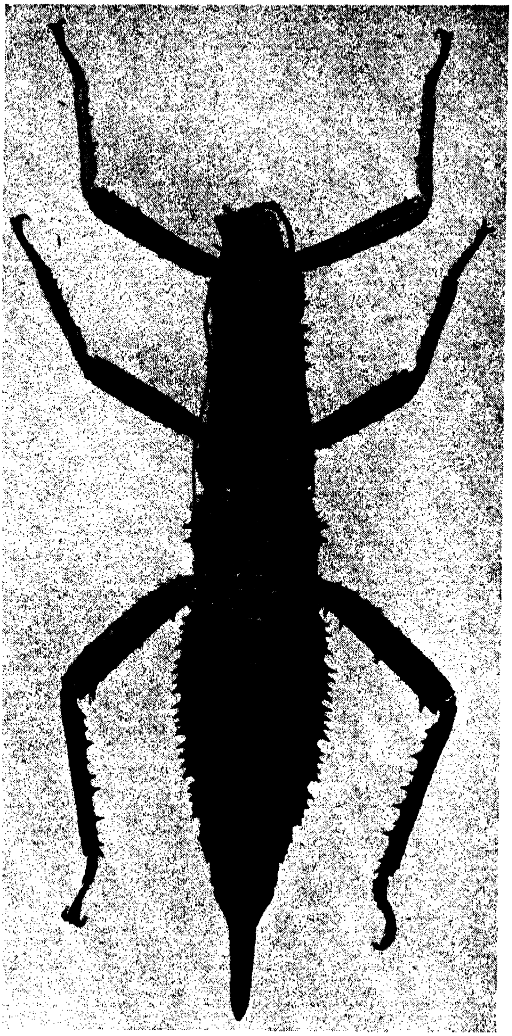
Note: There seems to be little point in differentiating between larva and nymph in insects, and these two names are, therefore, treated in the following pages as meaning the same thing, and the use of the word nymph is discontinued, so far as insects are concerned.



Cluster of stalked eggs of a Lacewing-fly.

Class Insecta

All groups of invertebrates so far considered, with the exception of small, restricted groups like the Protracheata and the Myriapoda, are wholly or mainly marine, the insects are confined almost entirely to the land and the fresh waters. Of the 650,000 or more species known



The female of *Eurycanthus horrida*, of Australia and New Guinea, showing clearly the head, the thorax composed of three segments from each of which springs a pair of legs, and the abdomen.

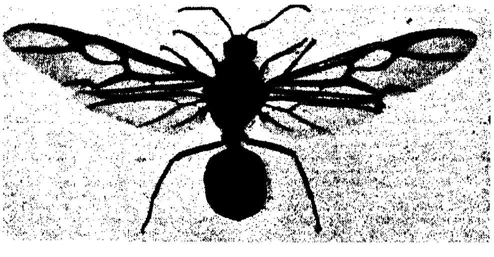
only a very few live in the sea, including some species of bugs of the genus *Halobates*, and a species of gnat living off the coasts of Samoa. There is a number of species living between tide-marks and capable of immersion for periods in sea-water, but they are not marine in the strict sense. On the other hand, insects have become adapted to practically every kind of situation existing on land or in the streams, rivers and lakes associated with the land masses.

For ordinary purposes the term "insect" is apt to include a motley collection of small, crawling animals, such as spiders, centipedes or even the terrestrial crustacea like woodlice. For natural history purposes it is necessary to be more precise.

To begin with an insect has three pairs of legs; all other animals have less (as in the quadruped or biped vertebrates) or more (as in centipedes, crustacea, spiders, and so on). The larvae of some mites have three pairs of legs, but later develop a fourth pair.

The body of insects is divided into three distinct parts, the head, thorax and abdomen. The head bears the eyes, a pair of antennae, and, on the underside, the mouthparts consisting of a pair of jaws, or mandibles, a pair of maxillae and a labium, or lip. The mouth parts are not, however, always recognisable in this manner; they undergo a great many changes according to whether the food is bitten, crushed or sucked. The thorax carries the three pairs of legs and, when these are present, the wings.

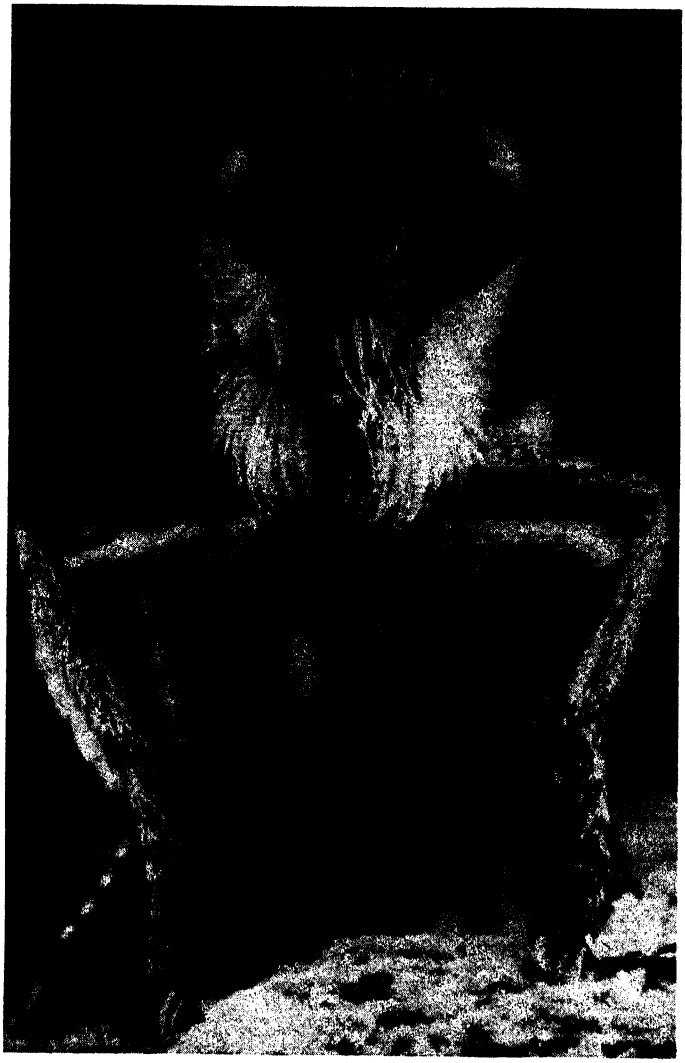
Although so few insects live in the seas to-day it is probable that their ancestors were originally marine (see Chapter 6). As we have seen, one of the chief characteristics of the Annelid worms is that the body is divided throughout into segments, and there is little doubt that insects sprang from a worm-like ancestor, for although not always obvious, an insect's body is also segmented throughout. Thus, the head consists of five segments, and although in most adult insects these have been fused into one so that the boundaries between them are lost, they can be seen in the developing embryo. In addition there are three composing the thorax and twelve making up the abdomen. The dis-



The Leaf-spinning Ant *(Oecophylla smaragdani)* showing the head, thorax and abdomen, wings and three pairs of legs of a typical insect.

covery of *Peripatus* (see Chapter 15) owes its importance, therefore, to the bridge it affords between the insects and their, presumably, worm-like ancestors.

The next most conspicuous thing about the typical insect is its eyes, but in the more primitive insects there are no eyes, or else they are rudimentary. In these the antennae act as organs of touch to guide the insects about; in others they also are lost and the front legs take on the function of antennae. Where the eyes are well-developed, however, they consist externally of a large number of six-sided facets. In dragon-flies, for example, there may be as many as 20,000 facets to each eye.



A greatly enlarged photograph of a Robber-fly, to show the large compound eyes.

Each facet consists of two crystalline lenses, a large outer and a smaller inner lens. Beneath these is a crystalline cone, enclosed in a dark pigment, and supported by a long rod surrounded by long nerve-cells filled with pigment and connected by nerve-fibres running to the brain. The nerve-cells correspond to the retina of the vertebrate eye and are known as retinulae. Other sense-organs possessed by insects are ears, organs of touch, taste and smell, and others which have no counterpart in the higher animals with which we are normally familiar. In all cases, however, there is a considerable variation as we pass from one group of insects to another. Many species, for example, are without ears, but they are strongly developed in those capable of producing sounds. Grasshoppers have ears on the shanks of the front pair of legs. In locusts they are on the first segment of the body, in blow-flies under the bases of the wings, in gnats at the bases of the antennae. In all cases, however, the structure of the ear is much the same, consisting of a pit across which is stretched a membrane or drum, and behind which is a cavity filled with air or a liquid.

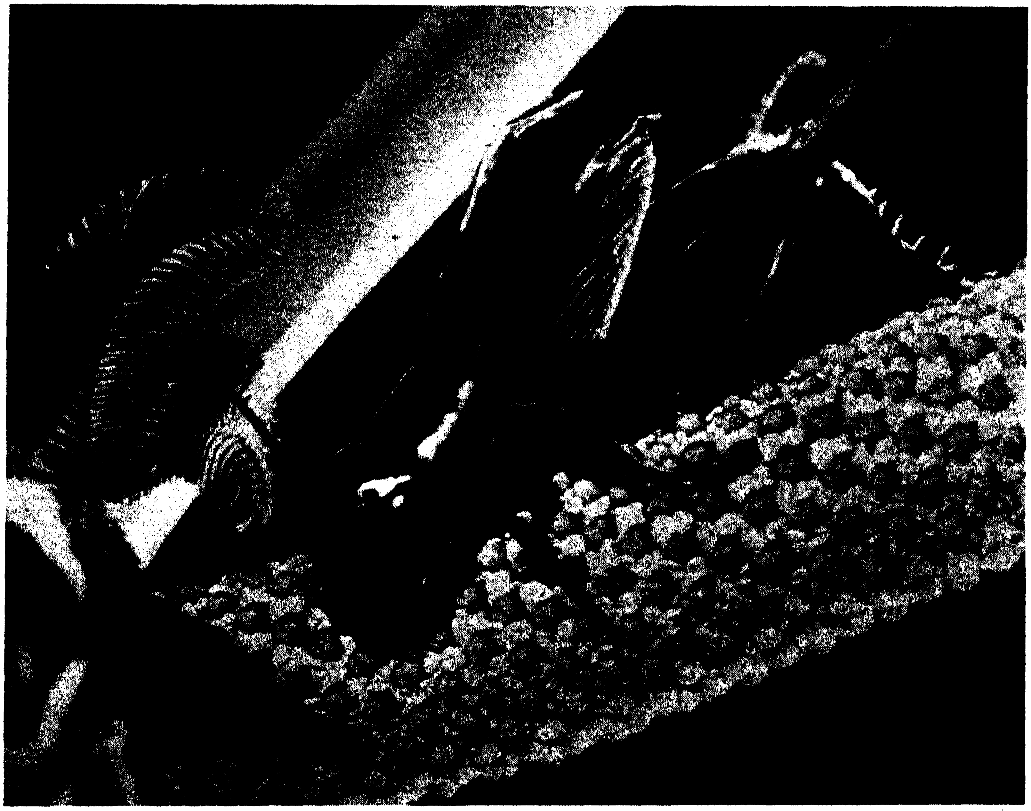
The organs of smell are lodged on the antennae, and consist of minute pits of which there may be a thousand on a single joint.

The sense of touch is in the minute hairs associated with the antennae, the maxillae and, the face, while the sense of taste is confined to the mouth parts.

In all cases the sense organs are connected by nerve-fibres with the central nervous system which, as in all invertebrates, consists of a nerve cord running the length of the body ventrally to the internal organs.

The legs of insects are uniform in structure though variously modified in accordance with habit. In the Praying Mantis the first pair are strongly developed pincers armed with stout spines and used as claspers for holding their prey. In the Mole Cricket and the burrowing beetles they are broadened and flattened for digging. In many insects, most markedly in bees, the front legs bear combs for cleaning the antennae. In the great majority of insects, however, the second and third pairs of legs are normal and conform to the typical pattern, consisting of four joints, the haunch, the thigh, the shank and the foot, with a small joint, the trochanter, between the haunch and the thigh. The foot consists of five small jointed sections terminating in a pair of claws.

Not all insects have wings although the great majority have. Some have never had wings at all, as the Silver-fish and the Springtails; others now wingless are obviously decended from winged ancestors. The most striking wings are found in butterflies and moths and the story of their unfolding and structure is typical for all winged insects. When a butterfly emerges from the chrysalis its wings are small and crumpled, a thing which can be readily observed. The butterfly then suspends itself by its legs to a convenient twig or leaf, allowing the wings to hang down. In a short space of time, each wing is seen to have grown more regular and to have lost its crumpled appearance. What has happen-



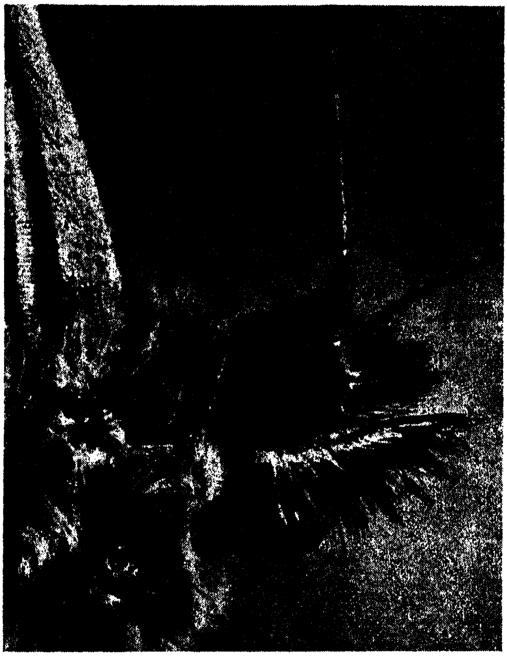
The female moth broadcasts scent from special glands on her body. The male, left of picture, receives the scent on fern-like antennae. To the right is a cricket photographed in the act of chirping by lifting its wings above its back and then sliding them back and forth, very much like a bow over the violin strings.

ed to bring about this change? The crumpled appearance is because the wings are at first sack-like, but as they dry the two walls of the sack come together until their inner surfaces are in close contact throughout. Between them run the veins, or nervures, which not only serve to strengthen the wings but to carry the air tubes.

There is a fair degree of variation in the shape of the wings, from the butterfly wing covered with overlapping scales, to the beetles with the front pair thickened and hardened to form elytra, or covers, for the second functional pair when at rest. In the flies and gnats, however, the second pair is reduced to dumb-bell-shaped organs, or halteres. On the other hand, the veining has a remarkable constancy in pattern, so much so that the small differences shown in passing from one to another are of great importance in classifying the species.

The respiratory system of insects is unique. Along each side of the body is a series of openings, called spiracles, leading into large air-tubes, or tracheae, running the length of the internal cavity of the body. From the main tracheae branches run out to all parts of the body.

How insects breathe.
This side view of a Poplar Hawk Moth resting on the trunk of a tree shows clearly spiracles, one to each segment of the abdomen, through which the insect breathes. Instead of lungs to receive the air, a system of breathing-tubes, or tracheae, branch off from the spiracles in a series of ramifications leading to all parts of the body.



Head of a butterfly.
Prominent features are the large compound eyes, the coiled tongue and the antennae. The palpi are seen directed forwards from a point under the eye. A portion of a wing can be seen at the top left hand side of the picture, with the wing scales clearly visible.

Instead of a series of closed blood-vessels with blood carrying oxygen from the lungs, as in lung-breathers, the air is carried to all parts of an insect's body direct through the tracheae. There is, however, a system of large spaces filled with blood, colourless or green, with the internal organs lying therein and bathed in the blood, An insect's heart, a tube-like vessel divided by valves into a series of chambers, lies dorsally to the other organs.

The life-history of a butterfly is well-known. From the egg is hatched the larva, or caterpillar, which feeds actively and later changes to the inactive chrysalis, or pupa, and from the chrysalis emerges the butterfly. Not all insects follow this plan, however. The rest may be divided into two groups: the primitive wingless species, the Apterygota, differ little from the moment of hatching to the fully-grown adult except in size, and growth is accomplished by a series of moults; the second group, including grasshoppers, locusts, and others, the Exopterygota, show the same growth by moulting except that there are perceptible changes at each moult, mainly concerned with the development of the wings. In contrast to these two groups, the forms having the same life history as the butterfly are called the Endopterygota.

The classification of the class Insecta is:

- Class Insecta.
  - Sub-class Apterygota.
    - Order Thysanura (Bristle-tails).
    - Order Protura.
    - Order Collembola (Spring-tails).
  - Sub-class Exopterygota.
    - Order Orthoptera (Earwigs, Cockroaches, Locusts, Crickets).
    - Order Plecoptera (Stone-flies).
    - Order Isoptera (White Ants or Termites).
    - Order Embioptera.
    - Order Zoraptera.
    - Order Psocoptera (Book-lice).
    - Order Anoplura (Lice).
    - Order Ephemeroptera (May-flies).
    - Order Odonata (Dragon-flies).
    - Order Thysanoptera (Thrips).
    - Order Hemiptera (Bugs).
  - Sub-class Endopterygota.
    - Order Neuroptera (Lace-wings, Alder-flies, Scorpion-flies).
    - Order Trichoptera (Caddis-flies).
    - Order Lepidoptera (Butterflies and Moths).
    - Order Coleoptera (Beetles).
    - Order Hymenoptera (Gall-flies, Saw-flies, Ichneumon-flies, Bees, Wasps, Ants)
    - Order Diptera (Flies, Midges, Gnats).
    - Order Siphonaptera (Fleas).

It is neither necessary nor desirable that the general reader should seek to memorise this long list of names, but it has a value in enabling him to find his way among the otherwise bewildering assortment of animals constituting the class Insecta. In particular, the names of the three sub-classes are an excellent guide to the characters of the main groups into which insects are divided.

Sub-class Apterygota

Insects of primitive organisation, in which growth is marked by a series of moults, with no great differences in the appearance of the animal following each moult.

These are the oldest and most primitive insects, their remains being found in the Devonian rocks. The earliest known forms were marine.

Order Thysanura (Bristle-tails)

The Silverfish is a typical Bristle-tail, about a quarter of an inch long, that lives in bread-bins, or among books, or in odd corners of the house, and which glides swiftly away when disturbed. The fish-shaped body is made up of the usual head, thorax and abdomen, the whole being covered by a layer of silvery scales that can be readily seen under a hand-lens. Projecting forwards from the head are two delicate antennae almost as long as the body, and projecting backwards are three bristle-like tails. The usual three pairs of legs are present on the undersurface of the thorax, but there are in addition pairs of small limbs on several other of the segments. Silverfish have feebly-developed eyes, but the well-developed tactile antennae are sufficient in a creature of nocturnal habit. They feed on bread and on the starch in book-bindings and on wall-paper (see p. 16).

Bristle-tails of the genus *Machilis* are found between tide-marks. Other species are widely distributed throughout the world under stones, in loose earth, and in caves.

Order Protura

The members of this order are extremely minute and live under stones, in peat and moss and under the bark of trees. They have no antennae but the first pair of legs are carried directed forwards and take on the function of antennae.

Order Collembola (Spring-tails)

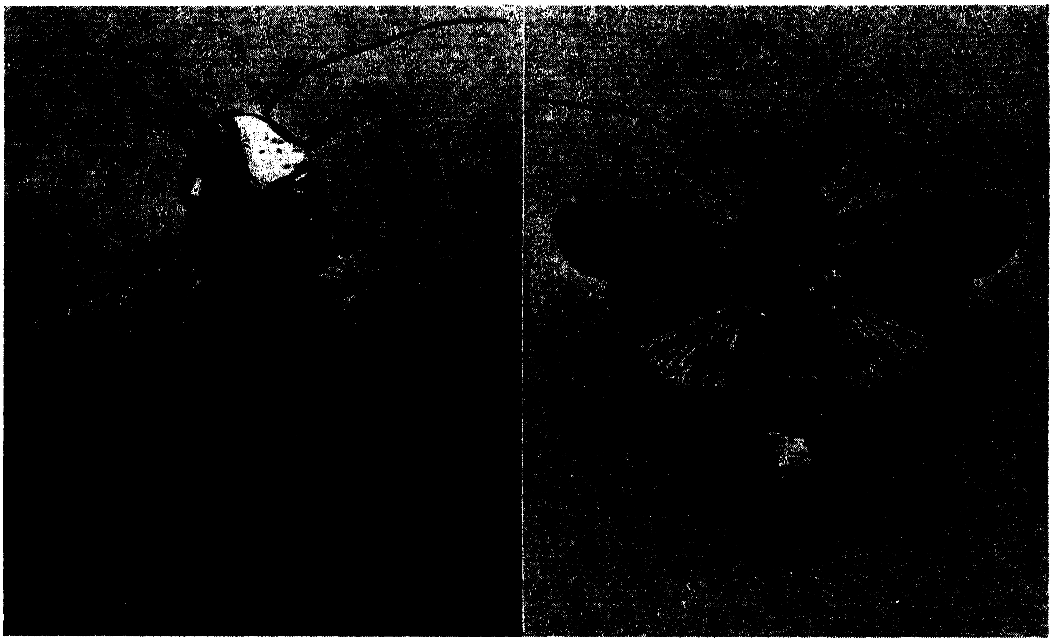
Spring-tails live under stones and leaves, usually in considerable numbers. Of minute size, they can be seen jumping in all directions when disturbed. The forked tail is folded forward and held in position under the body. When released it strikes the ground, causing the insect to leap into the air.

CHAPTER XVII

THE INSECTS I

THE SUB-CLASS EXOPTERYGOTA

To this sub-class belong those insects in which growth is marked by a series of moults, with a gradual development of the wings in passing from one moult to another



The Cockroach *(Blatta orientalis)*: On the left a female and characteristic egg-case; on the right, a winged male. The cockroach pest is disliked for the food soiled, and for the unpleasant smell disseminated, wherever it is abundant. Fortunately the numbers are reduced as compared with Carboniferous times, when of every ten insects nine were cockroaches. To-day they form less than one per cent. of the total insect population of the world.

Order Orthoptera
(Earwigs, Cockroaches, Praying Mantis, Stick Insects, Grasshoppers, Locusts and Crickets)

AFTER the Apterygota, these are the most primitive insects. Fossils closely resembling cockroaches have been found in the Carboniferous rocks. To-day, the species constituting this order are very widespread and numerous.

Earwigs can be clearly recognised by the large pincers carried at the end of the abdomen. The wings, too, are distinctive, the front pair being small and thick, serving as covers to the second pair which are large and membranous but folded up and stowed away beneath the small front pair when the insects are at rest. They feed on vegetation and are active mainly at night, hiding away under stones and leaves during the day.

The female earwig broods on and incubates her eggs like a domestic hen and when the young are hatched they creep in under the body of the female in a manner strongly reminiscent of the behaviour of chicks.

Cockroaches are natives of the tropics but a few of the thousand or more known species have been distributed throughout the world by man himself. The principal species so distributed are *Blattella germanica*, the German Cockroach, *Blatta orientalis*, the Blackbeetle, *Periplaneta*

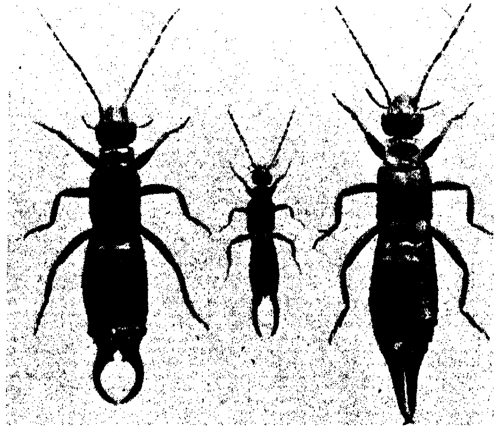
The Mantis preys on hornets, spiders, beetles, bumble bees, as well as many harmful insect pests.

americana, the American Cockroach, which have occupied buildings of all kinds throughout the world. In a wild state cockroaches live on decaying matter and hide away under stones. In the domesticated state they feed on kitchen refuse and hide in crevices in brick and woodwork.

The legs of cockroaches are long and slender, and a fair speed in movement is attained. The wings are either absent, or much reduced, but when present they are carried flat over the body, the second pair folded fanwise and lying beneath the first.

Some species live under the surface of the soil, leading to a burrowing habit which finds its most complete expression in the Australian species, *Panesthia lata*, in which the second and third pairs of legs particularly are broadened and armed with spines for digging. Usually an adult male and female live in a single burrow together with a number of their offspring. The adults, for the better convenience of life in a burrow, bite their own wings off deliberately to give themselves freedom of movement within a confined space. A number of eggs are laid at a time, contained in a fairly large case divided into two longitudinal chambers, each containing a series of eggs packed side by side.

The Praying Mantis is a striking and remarkable insect. The first segment of the thorax and the first pair of legs are much elongated, strengthened, and armed with stout recurved spines. The general colour of the body is green, the second pair of wings often variously coloured, so that the Mantis harmonises with the plants and flowers among which it lives. This camouflage is added to in some species by the presence of flattened leaf-like outgrowths from the thorax. The habit is to wait among the foliage with the fore-legs held up as in an attitude of prayer. As other insects approach they are watched carefully by the Mantis. When sufficiently close the

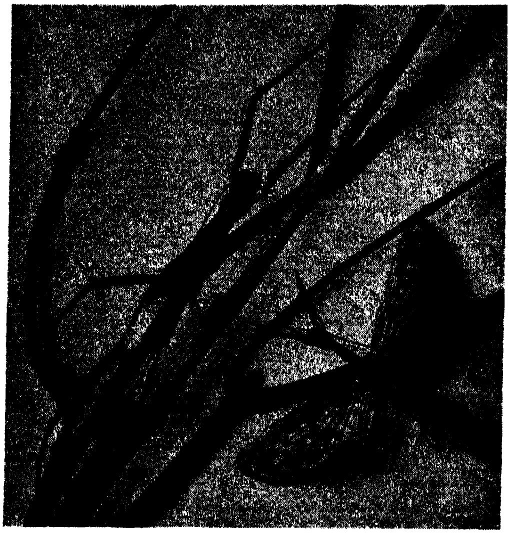


To the left, a male of the Common Earwig *(Forficula auricularia)*; to the right, the female. In the centre is the Lesser Earwig, *Labia minor*. It is an uncommon sight to see an earwig flying, but one worth watching for, to learn how the wings are disposed of when it comes to rest. Each wing folds up like a fan, and is then folded over twice before being tucked away under the front wing, the pincers being used to assist the operation.

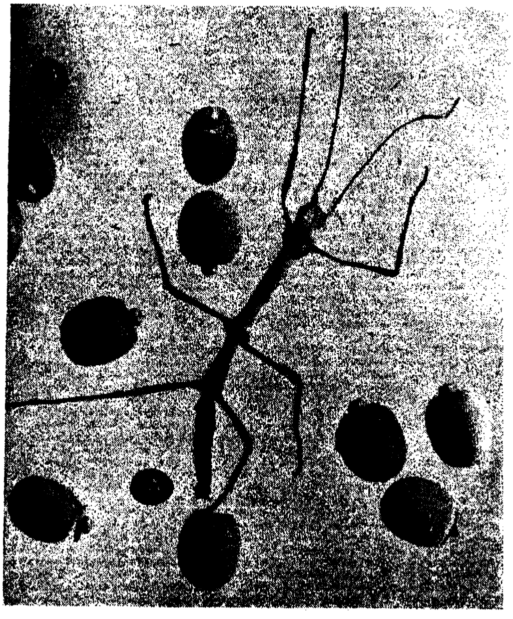
A Mantis poised for the attack, with the fore-legs folded ready to clasp the butterfly. The remaining legs are disposed to give the best support to the body.

fore-legs of the Mantis are extended and the intended victim is stalked with them. Suddenly the legs are folded on themselves and the victim is securely held between the shank and the thigh. The egg-masses of the Mantis are laid surrounded by a froth, which hardens on exposure to air, and attached to the stems and twigs of plants. The young on hatching attach themselves to a support by threads of silk secreted from the abdomen, and there remain until after the third moult, when the ability to secrete silk seems to be lost.

Stick Insects have an even better camouflage than the Mantis, but whereas the latter seeks obscurity in order to lie in wait for its prey, the vegetarian Stick Insects are concerned only with a disguise giving protection from enemies. The elongation of the first segment of the thorax, seen in the Praying Mantis, is carried to the other two segments in the Stick Insects, giving a long slender body which, with the green coloration, is an almost perfect representation of a twig. In addition, these insects remain quite still, especially during the day, clasping a stem with the last pair of legs and holding the body at an angle with it, while the other two pairs of legs are stretched rigidly out, looking like twiglets.



Tropical Stick Insects: the female on the left has the wings folded over the back, the male is shown as in flight. Stick Insects lay brown, seed-like eggs which are shot forth one at the time to drop to earth. It is an interesting coincidence that the eggs of an insect which looks like a part of a plant should themselves look like seeds. The eggs are produced largely by parthenogenesis, and a female may go on laying eggs for quite a time without the intervention of a male.



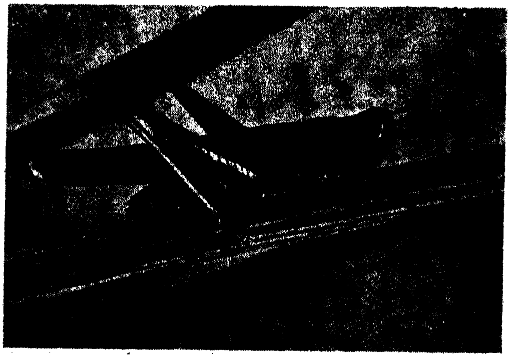
Eggs of the Stick-Insect, with a young insect newly hatched. The surprising thing is how this young insect could have been packed into so small a space.

Locusts as exposed for sale as food.

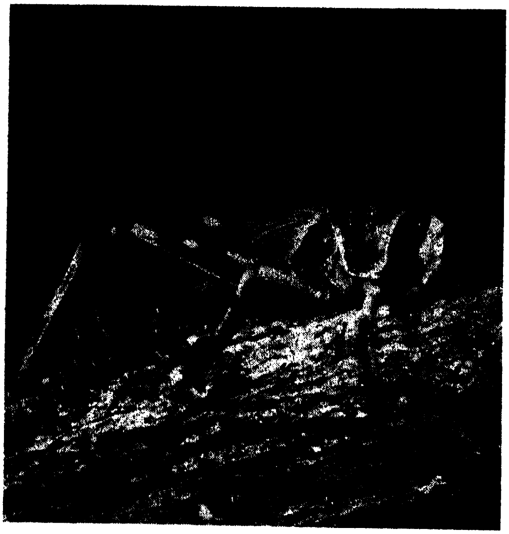
Related to the Stick Insects are the green Leaf Insects, in which the whole body, as well as the legs, are flattened and leaf-like, giving an almost perfect resemblance to the leaves among which they live. In some cases, the development of dark patches, rings and holes, adds even more to the resemblance.

The next group of this remarkable order contains the Locusts and the Short-horned Grasshoppers, in which the body is laterally compressed, the antennae short and the third pair of legs enormously developed to accommodate the powerful muscles by which these insects are enabled to make tremendous leaps. A further characteristic is the stridulating organ, composed of a row of knobs on the inner surface of the haunch of the hind leg which rubs against a strengthened nervure on the front wing to produce the characteristic "song". On the first segment of the abdomen a pair of crescentic openings, one on each side, mark the organs of hearing.

The females have a short, stout ovipositor for laying eggs in the earth at a short distance from the surface. The young when hatched resemble the parents except that they have no wings, and are known as 'hoppers'. Gradually, during



The Short-horned Grasshopper *(Stenobothrus bicolor)*.

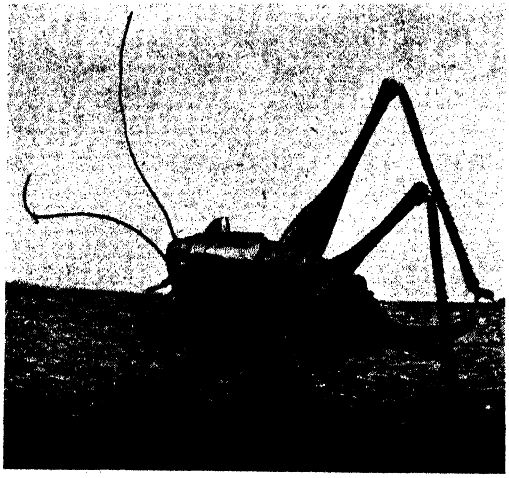


The Desert Locust *(Schistocerca gregaria)*, at the "hopper" stage. The wing bud can be seen just above the middle leg. In the solitary phase it is usually all green or brown, at this, the gregarious phase, it is black and yellow. After the next moult this insect becomes the winged adult.

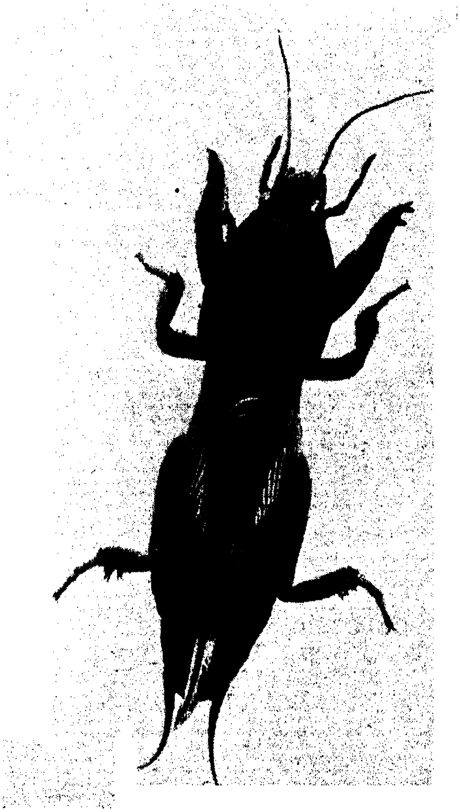
their lifetime, the wings develop until the adult or 'flyer' stage is reached.

Closely related to the Locusts and Short-horned Grasshoppers are the Long-horned Grasshoppers, or Tree Locusts. In these the antennae are long and curved over the body so that they extend beyond the tip of the abdomen. The ovipositor is long, slender and curved. The stridulating organ consists of a rasp carried on the undersurface of the left front wing, which can be scraped across a sharp ridge on the upper surface of the right front wing. The ears are on the shins of the first pair of legs. The best-known example of the Tree Locusts is the Katydid of North America.

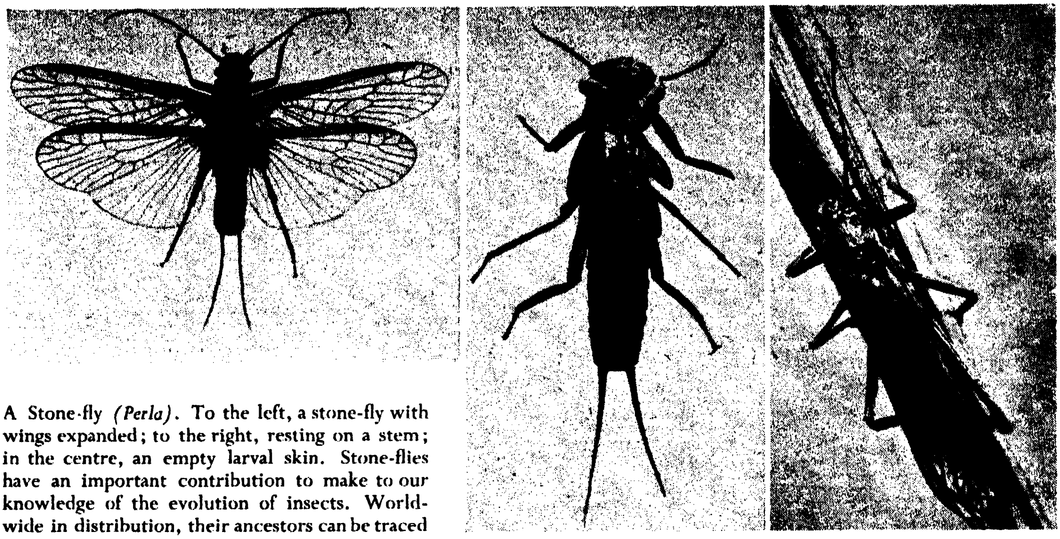
The tendency, seen in the Mantids and the Stick Insects and their relatives, to develop leaf-like structures is also carried to a high degree in the Long-horned Grasshoppers. In the South American *Tanusia brullei*, the front pair of wings is extremely leaf-like, even to the presence of markings such as are made in the tissues of real leaves by certain caterpillars. A contrast to this is provided by a South African species of *Myrmecophana* the larval forms of which are so



A British Long-horned Grasshopper *(Thamnotrizon cinerius)*. Like the cricket, it often "sings" at night. Two New Zealand species of Long-horned Grasshoppers, *Pachyrhamna fascifer* and *P. acanthocera*, are among the largest insects, the first measuring up to nine inches in length and the second up to fourteen inches.



The Mole Cricket, with its body modified for digging. As in the mole the front legs are flattened and shovel-like.



A Stone-fly *(Perla)*. To the left, a stone-fly with wings expanded; to the right, resting on a stem; in the centre, an empty larval skin. Stone-flies have an important contribution to make to our knowledge of the evolution of insects. World-wide in distribution, their ancestors can be traced back to the Permian, yet in spite of their antiquity and primitive character they pass through a brief resting period just before the final moult which clearly foreshadows the metamorphosis characteristic of the more advanced Endopterygota.

like ants as to deceive even an experienced entomologist.

Crickets are very similar in form to the Long-horned Grasshoppers, though less graceful in build. Mainly nocturnal in habit, their colour is a dingy brown or black. Their food is extremely varied, live or decaying vegetation or animal matter, or even members of their own species.

Gryllus domesticus, the House Cricket, is, like the cockroaches, almost a domesticated animal. Its wild habits are unknown.

The King Cricket of Australia, *Anastostoma australiae*, is a heavily-built, ferocious-looking insect, wingless and with enormous jaws, which burrows in the ground.

The Mole Cricket, *Gryllotalpa*, is perhaps the most remarkable member of a very remarkable family. The body is squat and strongly built, the first segment of the thorax is heavy and shield-like, but the most striking part of this burrowing insect is the first pair of legs. These are shortened and broadened, especially the shins, which are shovel-like with four stout teeth at the end of the blade. The first joint of the foot is built like the blade of a penknife and is capable of moving over the edge of the shin in the manner of the blades of a wire-cutter. With it the Mole Cricket is able to cut through small roots which might otherwise impede its digging.

Order Plecoptera (Stone-flies)

Stone-flies are of fairly small size, inconspicuously coloured and of sluggish habit. The immature stages are aquatic, the adults winged. The antennae are long and slender, the front wings are narrow and, when the insects are at rest, cover completely the much broader hind wings, which are folded fan-wise over the abdomen. In the aquatic stages respiration is by gills formed as outgrowths of the tracheal system from the segments of the thorax, or from other parts of the body.

THE TERMITES

by

DR. THOMAS ELLIOTT SNYDER

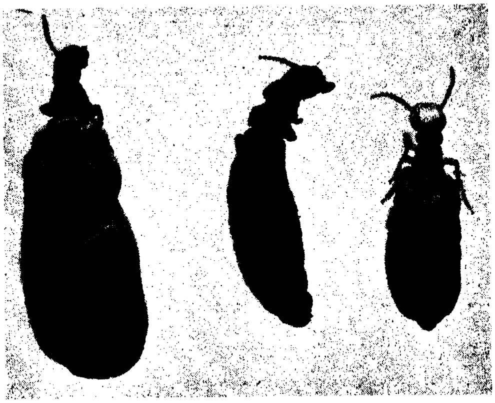
Order Isoptera

The termites display an elaborate communal society in an old, primitive, more plastic form of insect life, paralleling the society of the more highly specialized social insects—the ants, bees, and wasps. This communal life among insects occurred long before the evolution of man and his civilization; termite society was precursor to that of man. Man later has passed through arboreal, cave and hut stages to the older elaborate architectural wonders of the higher bees, wasps, and termites. In consequence egoistical man evidences great interest in these social insects.

The termites of the world constitute about 2,000 species; they occur in all the warmer regions of the world, but reach the greatest number and height of their development in the tropics; the 50 degree parallels of latitude and the mean annual 50 degree isotherms outline their distribution. Sixty-five fossils have been found embedded in rock, amber, or gum copal; 59 living and 10 fossil species occur in the United States; 3 living and approximately 30 fossil species occur in Europe. In prehistoric times termites had even a wider distribution.

Termites are closely related to the roaches, but are much younger geologically; termite fossils occur in all deposits from the Lower Tertiary on. With the roaches they are offshoots of the more primitive group, but termites have become more highly specialized with the social life and caste system, whereas roaches are merely gregarious; termites might be called "social cockroaches".

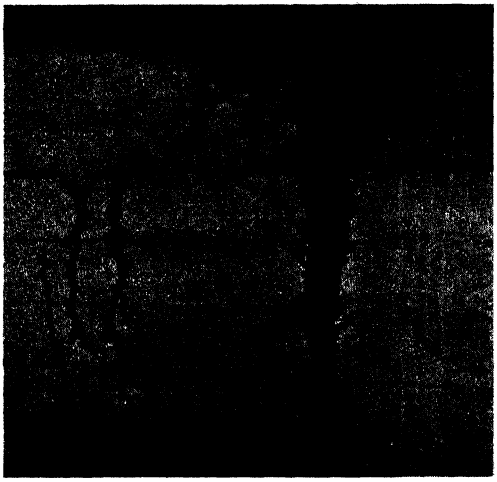
Termites are polymorphic: there are males and females and three types of reproductive forms—the monogamous winged with functional eyes, and the polygamous forms with wing pads or the wingless castes, as well as a series of intermediates, including fertile so-called "soldiers". There may be three types of sterile male or female soldiers and two types of sterile male or female workers. Very great diversity of kinds occurs and the greatest structural differences occur between the castes; many intercastes between workers and soldiers occur.



The types of queens of the common subterranean termites of the United States, (*a*) macropterous form developed from the winged adult, (*b*) the brachypterous form, and (*c*) the apterous form. Each female has a male of the corresponding type.

Comb from fungus garden of termite nest in Java; the termites eat the small globular "cauliflowers".

A large queen of a fungus-growing termite of India; immobile, she is imprisoned in the royal cell.



Earth-like shelter tubes built by termites over concrete wall to reach wood above.

Among the more primitive termites, no worker caste occurs; and in one highly specialized termite, no soldier caste occurs. As a rule, where workers occur they constitute the caste most numerous in the colony for the greater proportion of the year. Where soldiers occur, they constitute but a small proportion of the colony. At certain seasons of the year the reproductive types occur in very large numbers.

Among termites there are races and subspecies and possibly crosses or hybrids due to interbreeding among closely related species. There is interbreeding in nature between the different reproductive types.

The caste system and the occurrence of sterile forms are difficult to explain under the various theories of evolution. But there are several theories as to the determination of castes among termites—the genetic, that the castes are predetermined in the embryo; the nutritional, that food differences are correlated with the castes; and more recently the inhibitional, that the reproductive castes and soldiers give off exudates containing inhibiting substances, each caste tending to inhibit the development of the same caste by a hormone regulation.

Termites are soft-bodied, winged and wingless, social insects with biting mouth-parts; while superficially ant-like in form, they are not true ants. They have a broad thorax and their wings are usually about the same size. The eggs are laid singly except in a primitive Australian species, which lays the eggs in a mass similar to that of the roaches. There is no pupal stage, but there are quiescent stages of short duration, during the moults to the adult caste. While metamorphosis is incomplete, there are marked changes during growth from larva to adult. Termites mate in a manner similar to the roaches, to which they are closely related.

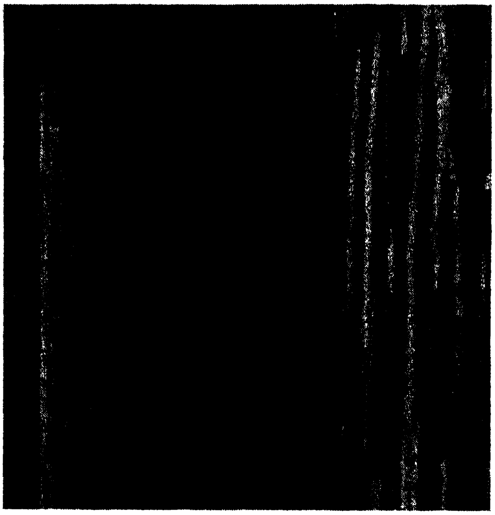
Termites are not dominant insects and do not crawl about in the open. They are usually subterranean or secluded in habitat. They have been forced by their chief enemy—ants—to "dig in", in order to survive, and in consequence live a concealed life in wood, the earth, or in earthlike shelter tubes; but termites have in consequence "underrun" tropical countries. There are a few exceptions where tropical termites are harvesting in habit and come above ground into the sunlight; these forms, however, are dark-colored and have eyes. Normally termites construct earthlike shelter tubes whenever they come above ground in search of food or water to conserve the humidity so necessary for these soft-bodied insects. Often these tubes run up coconut trees in the tropics to great heights.

There is a division of labor and the occurrence of both reproductive and sterile forms; the workers have evolved from the soldier caste and care for and feed the young, the reproductive forms and the soldiers. The soldiers defend the colony when invaded by ants. Primitive termites have sawtooth mandibles, but later there evolved a special gland in the front of the head with an acidulous secretion which superseded the mandibles in many termites. Among the termites intermediate between the primitive and highly specialized form, both mandibles and frontal glands function. In the nasute termites, a viscous liquid is ejected as a special, very effective form of gas defense.

In other highly specialized termites the mandibles are markedly asymetrical, and could not be used for biting, but are used to audibly snap or flip the insects away from danger; or they may be merely used for signalling, to warn of danger. The colonies or nests of termites are constructed of earth or earthlike material in the ground, as mounds on the ground, as carton tree nests, or within the wood. In the tropics, whole villages of termite nests dot the landscape; these nests are hard and often in Australia oriented with reference to the sun's rays. There has been a progressive development in the structure of termite nests comparable to that later followed in the structures of man.

Within the more pretentious concentrated nests, there is an orderly arrangement of cells and galleries with a special royal chamber for the reproductive forms and nurseries in which the young are cared for. Queens of tropical termites reach enormous size; with the kings, they may live as long as 25 years. In the higher fungus-growing group of the Orient and Africa, queens may reach 4 inches in length; they are immobile and are imprisoned in a cell. In these nests galleries lead to fungus gardens, wherein edible mushrooms are grown by the termites. Mound nests in South Africa have been venerated by the aborigines for hundreds of years.

The chief food of most termites is cellulose, which they obtain from living or dead wood and other vegetation. To digest this cellulose, termites have within their intestines thousands of symbiotic protozoa which contain enzymes that render it available for food.



Oak flooring damaged by subteranean termites. Note that the injury is not observable from the top surface.

In the nests of many termites are degenerated but oddly-shaped, specialized, physogastric forms of insect life, inquilines, which have various exudate glands; they are protected and cared for by the termites, which eagerly lick this exudate. Occasionally termites are cannibalistic; they obtain body secretions by constantly licking each other, and there is continuous exchange of nourishment. By injecting poison dust into the galleries of termite nests, they can thus be killed because of this "grooming" habit.

Book destroyed by termites, showing living termites in it.

Termites cannot reason and are guided by hereditary instincts and tropisms, principally hunger, sex, and fear. They follow each other by means of body odor and probably communicate by means of vibrating the body, detectable through the earth. For this reason termites will not work in wood near vibrating machinery.

The colonizing flight of termites, usually occurring in the tropics after a rain, is a very interesting phenomenon. Apertures are opened in the mounds and suddenly the air is alive with fluttering hordes. This flight is not a nuptial flight, since only after losing their wings do surviving males and females mate. Many forms of animal life prey upon termites during this flight.

Ordinarily while in their tunnels, termites shun the light or lack of humidity; in the colonizing flight, however, they emerge into the sunlight, climb to elevations and fly. After the flight, generally followed by the shedding of their wings, they seek shelter in the earth. From insects that choose close quarters in the soil (thigmotropic), cling to the earth (geotropic), and avoid light, they change to insects that seek light (phototropic), avoid close quarters in the soil, and seek elevations, and again change these three actions to the earlier condition, all within a few hours.

The superorganism concept referring to the social insects is that diversity of castes within the species has been so perfected that the colony may be regarded as a single living creature, subject to the same simple laws. The termite colony as a whole is as the human body, the workers representing the red blood corpuscles and the soldiers the white, with the outer surface of the termite nest analogous to the human skin. It has been stated that the queen is the brain of the colony, whereas more probably the workers are the motivating caste. It would seem to be more rational to compare the termite colony to the multicellular animals, such as the sponge, rather than with highly complex organisms such as man.

By man's disturbance of the balance of nature in felling and clearing forests and woodlands, his cultivation of the fields, and encroachment of civilization, evidenced by more extensive building operations, drainage and irrigation, termites have been forced from their natural habitats and have been driven to attack the woodwork of buildings and other works of man for both food and shelter. Man has changed the status of termites from the role of scavengers to that of pests; they cause a loss of forty million dollars each year in the United States alone.

Ninety-five per cent. of termite damage in the world is caused by the subterranean type. Practically all damage can be avoided by proper construction. Much damage by termites to substances not containing cellulose is due to the fact that these materials are in the path of the termites. Damage to metal and other impenetrable material is caused by the corrosive action of moisture brought up by subterranean termites with the earth and excreted wood from which they build sheltered runways.

Insulating untreated wood from the ground by means of concrete or metal barrier shields offers both permanent prevention of, and a remedy for, damage by subterranean termites. The impregnation of construction timbers with chemical preservatives and screening buildings are the most effective method of preventing damage by dry-wood termites, which do not need much moisture for their existence and attack wood direct, without ground contact. Buildings can be termite-proofed at a relatively small cost—from 1 to 2 per cent of the initial cost in the case of subterranean termites and 10 per cent. of such cost in the case of dry-wood termites. City building codes with brief termite-proofing provisions in the mandatory sections are the logical answer to the termite problem. Where structural changes are impractical in the case of termite infested buildings, poisoning the soil about the foundation offers promise. Hence, it will be seen that man can control termites by either structural or chemical means.

Order Embioptera

This order includes a comparatively few species of insignificant insects, confined to the tropics. Very little is known of their habits, but such knowledge as we have reveals points of sufficient interest to be described here.

Seldom more than half an inch long, they have long delicate antennae and an elongated body. The male is winged, the females wingless. The basal segment of the foot in the front pair of legs is swollen and capable of producing silk. Most of the species live in small colonies. An Indian species, *Embia major*, builds a complicated system of tunnels lined with silk. There is nothing of the social organisation found in termites, but the condition found in *Embia major* suggests one of the early steps in the evolution of social colonies of insects.

Order Zoraptera

Included here are a handful of species of minute insects, 2 to 3 mm. long, recalling some of the primitive Apterygota. Several are wingless, but some have wings like those of termites. A simple social system has been evolved, showing some resemblance to that of the termites themselves. And curiously enough some species live in termite's nests, although most live in rotting wood.

Order Psocoptera (Book-lice)

Here are grouped a number of species of small, plump insects characterised by a pair of chisel-like organs associated with their mouth-parts, used for digging into the bark of trees. Some of the species, like the cockroaches and crickets, have become almost domesticated. The Book-louse, *Troctes divinatorius*, a wingless species, is found in old books, as well as in household rubbish. In addition to this and other species which feed on the paste in book-bindings, old paper, entomological collections, and such things, there are those that feed on fungi and lichens and probably serve to distribute their spores.

Some of the larger Psocoptera resemble small moths. Indeed, some of them carry the resemblances further in that the wings are covered with scales bearing a slight similarity to those of the Lepidoptera.

Order Anoplura (Lice)

Lice fall into two natural groups, the Biting Lice or Mallophaga, with biting mouth-parts, and the Sucking Lice or Sipunculata, with mouth-parts modified to form a sucking tube.

The Mallophaga are often referred to as bird-lice because they are found almost exclusively on birds, although they also occur on mammals, especially domesticated ones. They are small, seldom more than a quarter of an inch in length, flattened and wingless, and feed on fragments of feathers, hair and the cast-off epidermal cells. They cause injury to their hosts through the scratching of their claws as they move about the body.

Bird-lice can only be passed from one host to another by contact, which means that each species of bird has its own peculiar species of lice. Consequently, the view is held that a study of the relationship of the lice will give a clue to the affinities of the birds themselves; that as the species of birds evolved from a common ancestor, so did the parasites living on them.

The Sucking Lice feed on blood. Some are carriers of disease, carrying the infection from one host and introducing it into the blood of another.

The same exclusiveness is found in Sucking Lice as in Bird-lice. Thus, the body-lice and head-lice of man are found, in addition, only on apes and certain monkeys. The species of another genus, *Polyplax*, are found only on rats and mice. And so on.

Frame residence in American tropics with metal termite shields in place on foundations.

Order Ephemeroptera (May-flies)

May-flies are familiar insects in the vicinity of rivers and lakes throughout the world. Their life-history is peculiar in that the larvae, which are aquatic, may take up to three years before emerging as the perfect insect. This final stage lasts, however, a few hours only, or a day or two at most.

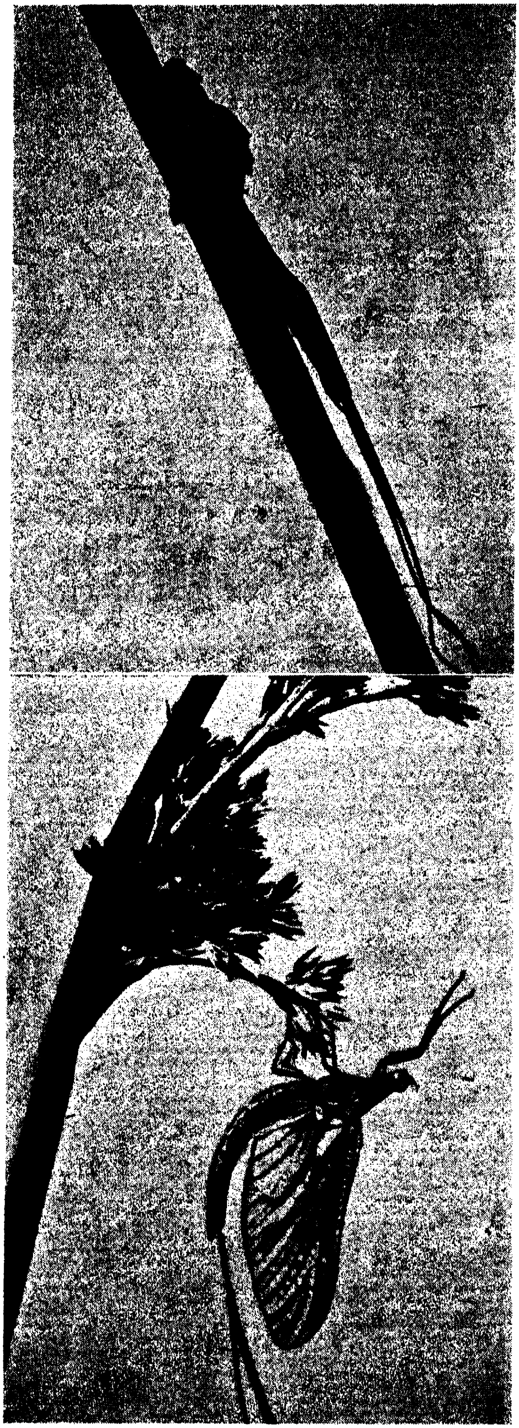
In spring or early summer, large numbers of them appear in the evening and engage in a nuptial or mating dance, the whole crowd of them fluttering upwards and then slowly descending. This goes on during the night and the females, as they are fertilised, return to the water to lay their eggs on submerged stones in sticky masses. No food is taken once the insect has emerged from the larval state.

During the dance the May-flies are preyed upon by birds, and, on the surface of the water, they are readily devoured by fish. For the latter reason several of the fishermen's 'flies' are modelled on them.

From the eggs hatch small, active larvae, for the most part vegetarian. At first they appear to breathe through the skin, but later they develop abdominal gills. After many moults, during the course of two to three years, rudimentary wings appear. Finally, the larva climbs to the surface of the water, a split occurs down its back and the winged May-fly appears. The empty larval cases may be seen, at such times, floating in vast numbers on the surface of the water. The winged May-fly, after emerging, flies a short distance away, settles and sheds another skin, a thing unique among insects.

Order Odonata (Dragon-flies)

Dragon-flies always compel attention not only for the delicate beauty of their colouring and the fairy-like quality of their wings, but also for the bewildering rapidity of their flight. Nearly 3,000 species are known, and although distributed throughout the world they are most abundant in the tropics. Their build, again, is distinctive, with the large head and prominent eyes, comprising up to 20,000 or 30,000 facets, and the long slender abdomen. The wings are hard and glossy, both front and hind wings being approximately the same size, with abundant nervures mainly running transversely. The head, which is freely movable on the neck, bears a pair of short antennae and a pair of strong biting jaws, the rest of the mouth-parts forming a trap for capturing insects. The legs are not much used for walking, but serve to hold the larger prey. Eggs are either scattered on the water, or are



The May-fly *(Ephemera vulgata)*: above, a skin discarded after the insect has attained the winged state. The May-fly is a sombre grey or brown, has a slender body, with a pair of delicate antennae on the head and three long, slender tails directed backwards from the tip of the abdomen. The front wings are triangular and markedly larger than the hind wings.

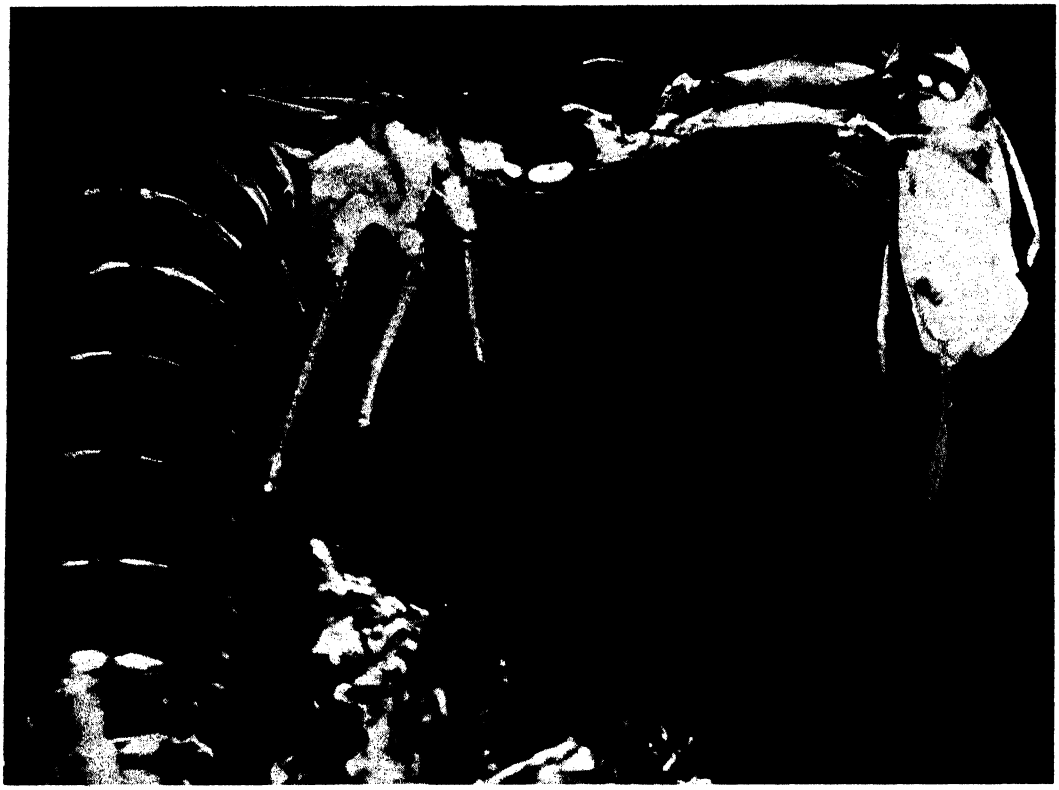
washed from the female's abdomen as she dips it while flying; sometimes they are enclosed in gelatinous strings which adhere to submerged objects; sometimes they are laid in slits cut with the ovipositor in the stems of water plants.

From the eggs hatch out pro-nymphs, so-called on account of their incomplete appearance, which immediately cast their skins to become free-living larvae, differing markedly from the fully-grown dragon-fly except in their predaceous habits. For the space of one to five years, the larvae prey on almost any animal from insect larvae, worms and tadpoles to small fish. They are of sombre colour, harmonising with their muddy surroundings, and their habit is to lie in wait for their prey, which they capture by rapidly shooting out the 'mask' (see page 270). The method by which the larva of a dragon-fly catches its food recalls strongly that used by frogs and chameleons. In all three cases there is the motionless lying in wait, the same swiftness in striking and accuracy of aim. The mechanism is, however, markedly different in the dragon-fly. The mask consists of a jointed and much elongated lower lip ending in a powerful pair of pincers. When at rest it is folded upon itself and lies over and completely covers the undersurface of the head. Hence its name.

The larva moults probably a dozen times, and when the day comes to end its aquatic life it climbs the stem of a water plant and comes to rest some distance up from the surface of the water. The skin splits down the back and the perfect insect begins to make its appearance. The thorax first appears and, swelling up, causes the skin to split still further. Then the head emerges and is thrown right back so that it hangs well down. In this position the dragon-fly is attached only by the tip of the tail to the dried skin. Then the head is jerked forward again and the tip of the abdomen drawn out. After this a period of time must elapse while the wings expand, dry out and harden.

Dragon-flies, like their larvae, are insatiable feeders on other insects. During the feeding flights, each one keeps to its own territory. If

Resembling some prehistoric monster, the Dragon-fly larva lives beneath the water and travelled about by jet propulsion long before man ever dreamed of such an invention. The larva has an apparatus at the rear of its body by which it can project water with a strong force, propelling the insect through the water at a rapid speed.



A rare scene: a Dragon-fly larva photographed in the act of catching a Water Boatman. The Dragon-fly larva has a folding underlip, called the mask, which is shot out with lightning-like speed to catch its victim.

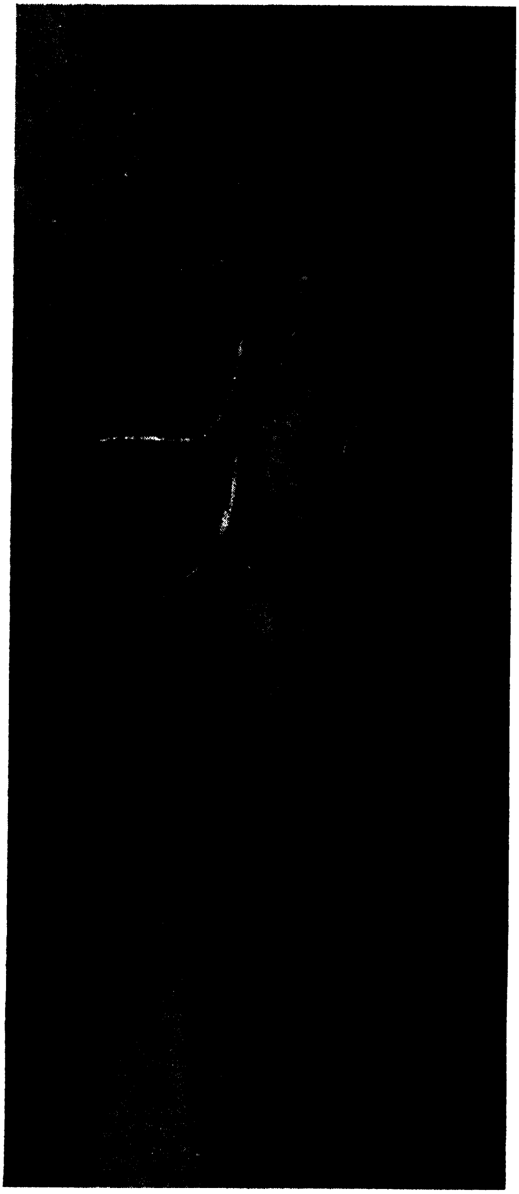
another dragon-fly ventures therein the established owner of the beat will make a quick feint at it and drive it off. There is obviously a survival value in this. Not only does it ensure an adequate food supply for each individual by spreading the population evenly over the countryside, but there is also the safety element, of preventing too great congestion, thereby rendering the insects an easy target for their enemies.

The largest dragon-fly to-day, *Megaloprepus caerulatus* of Central and South-America, with a wing span of seven and a half inches, is only a quarter the size of the giants of the Carboniferous period.

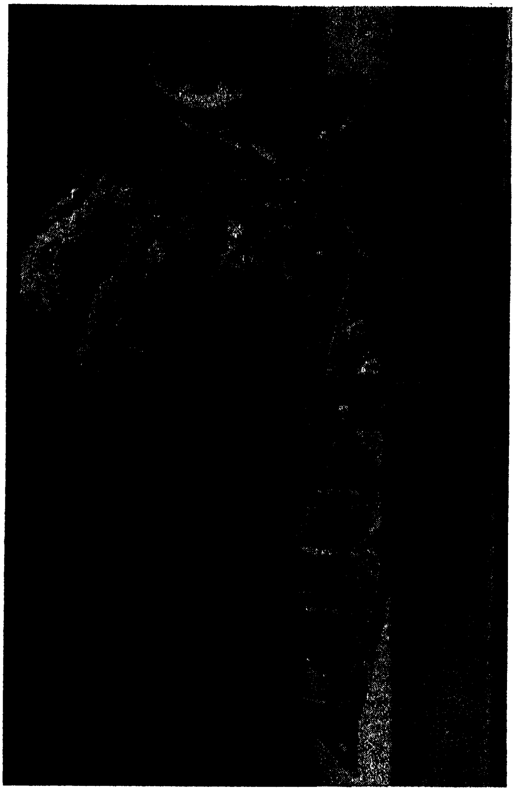
SPEED IN INSECTS

Dragon-flies are among the fastest insects, though they fly at nothing like the speeds with which they are credited, for some observers have declared them capable of speeds up to 90 miles an hour. A number of attempts have been made to record the speeds of insect flight, and because of the many difficulties involved these records tend to show serious discrepancies even for the same species. According to the most reliable results obtained, however, the fastest flight is that of the Aeshna Dragon-fly, with just under 16 miles an hour, while the Demoiselle Dragon-fly is capable of a little more than 3 miles an hour. Except for the large dragon-flies, the hornet (nearly 13 miles an hour) and the Humming-bird Hawk-moth (11 miles an hour), with other comparable insects whose times have yet to be accurately recorded, the speeds of the great majority of insects are less than 10 miles an hour, with the honey-bee doing 6 miles an hour and the house-fly, 4.5 miles an hour.

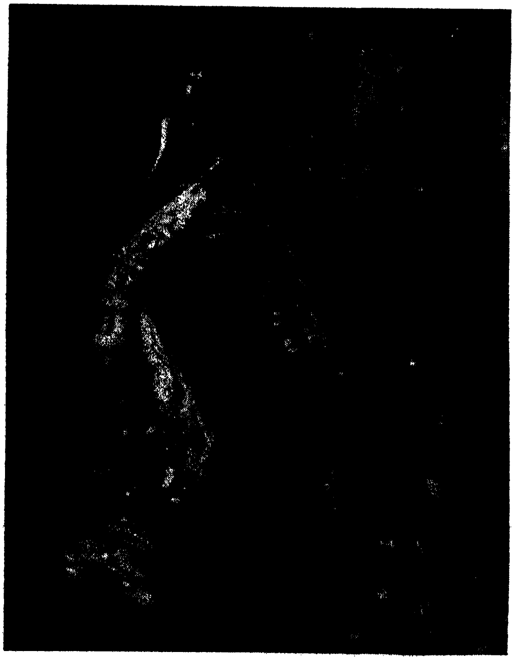
On the other hand many insects can manœuvre with great skill and it is possible that either they are capable of higher speeds—in short



At a certain stage in the life of the Dragon-fly larva, it crawls up out of the water on to a reed or blade of grass, and there it clings until the skin splits down the middle of its back and the perfect Dragon-fly emerges.



Dragon-fly in the act of breaking out of the back of the larva-case.

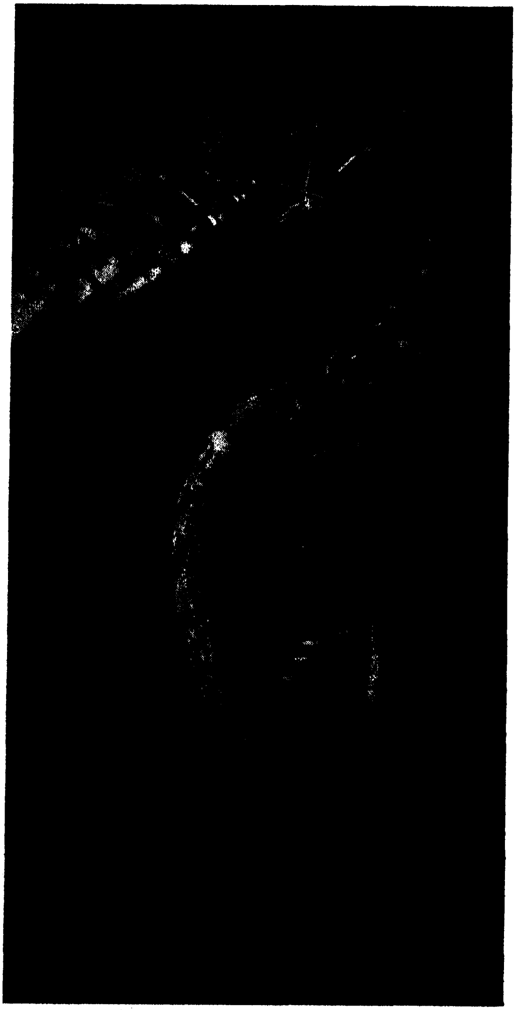


The emerged Dragon-fly hangs downward with part of its body still in the larva shell. In this position it remains until its legs are strong enough to support the insect on the reed without the aid of the shell from which it emerged.

The Dragon-fly's legs are now strong enough to support it, so the insect has emerged completely from the larva shell and will remain in this position until its wings are fully developed.

bursts—than those given here, or that their aerobatics deceive the human eye, and that we must await some more accurate means of timing their flight.

Some years ago, the entomological world was startled by a report that the American Bot-fly could travel at a speed of more than 800 miles an hour. This has been proved to be incorrect, and it is thought that the revised estimate of 25 miles an hour is, in fact, excessive. To begin with, any insect flying at such a speed would be invisible; secondly, since a large beetle has been known to shatter the wind-screen of a car (travelling at 30 miles an hour) by flying at it head on, we should expect a Bot-fly travelling at such a high speed to pass through many of the lighter obstructions like a rifle bullet. Yet in spite of its general air of improbability, and the fact that this high figure has been proved a myth, the story of the amazing flight of the American Bot-fly has not yet died a natural death.



A newly emerged Dragon-fly clings to a reed stem until its wings become fully developed to take flight.

CHAPTER XVIII

THE INSECTS II

THE SUB - CLASS EXOPTERYGOTA

The orders Thysanoptera and Hemiptera, with an account of the biological control of pests

Order Thysanoptera

THRIPS are very minute. Some of them reach half an inch in length, but the majority are very much smaller, about a fiftieth of an inch. They are vegetable feeders and, being very numerous, the damage they do to vegetation, and especially crops, is very great. For example, they will actually produce sterility in oats. It is not the large, conspicuous insects, therefore, which necessarily do the most damage.

Thrips occur plentifully on flowers, foliage, dead leaves, and fungi. They are distinguished by the narrowness of the wings, which are reduced to one or two nervures fringed with hairs. The mouth-parts are modified for piercing and sucking.

Again, in this order, there is a foreshadowing of the metamorphosis found in the Endopterygota. When first hatched the young are like the parent but wingless. After two or three moults the wing-pads appear on the thorax, and at this stage, in many species, the developing thrips make their way into the earth and lie quiescent. The usual method of reproduction is by parthenogenesis. In all species the males are much less common than the females, and in some species they are extremely rare.

Order Hemiptera (Bugs)

The order Hemiptera contains a very diverse assortment of forms, from the more repulsive to those so beautifully coloured as to rival the butterflies and moths in appearance. It will be convenient, therefore, to consider them under their sub-divisions: the Heteroptera, or True Bugs, containing the Land Bugs and Water Bugs, and the Homoptera, containing the Cicadas and Leaf-hoppers, together with the Leaf-suckers, Plant-lice and Scale-insects.

A typical Bug.
Tropicoris rugipes, a large plant-frequenting bug which feeds largely on insects and hence is classed as beneficial.

Sub-order Heteroptera (True Bugs)

In the True Bugs the first segment of the thorax is usually large with the head much sunk into it. The abdomen is oval and flattened and the front pair of wings are stiff and horny, becoming membranous towards the tips. All members have the ability to emit an unpleasant odour from special glands in the front part of the abdomen.

Land Bugs

The Pentatomoid bugs, known as Shield Bugs

Shield or Stink Bugs on a stem. In spite of their numbers they are little known, largely because they tend to be coloured like the plants on which they live, and also because they do not move about in swarms. Moreover, they usually keep on the move, and for this reason do not, as a rule, constitute plant-pests since they do not stay long enough to do any considerable damage. The species shown is, however, an exception to this.

or Stink Bugs, include a very large number of species. These alternative names provide clues to the recognition of the bugs. The name Shield Bugs refers to the triangular extension of the thorax, known as the scutellum, which overlies the abdomen to a greater or lesser extent. In some bugs the scutellum, as in *Ceratocoris horni*, covers the whole of the abdomen. The term Stink Bugs is ambiguous as all bugs give off an unpleasant smell. This name is, however, more used in America because of the accident of eating wild fruit with the bug resting inconspicuously on it—with unpleasant results.

Shield or Stink Bugs can be found readily among almost any kind of vegetation, and can be collected by holding a sheet of paper or a piece of cloth under the bough of a tree and giving it a sharp tap with a stick. To the beginner, using this method, it is a matter for astonishment to find how easily Shield Bugs, and many other kinds of insects, come tumbling from the leaves.

Some of the Shield Bugs constituting pests are: the Hottentot Bug (*Eurygaster maurus*), dark brown with two light spots either side of the scutellum, which in some parts of Europe constitutes a pest of wheat; the Cabbage Bug (*Eurydema oleracca*) of Europe and the Harlequin Bug (*Murgantia listrionica*) of America, both occasional pests on cabbage.

The Chinch Bug (*Blissus leucopterus*) is a pest of grass, wheat and other grain crops. About one-sixth of an inch long, black and white in colour, it may invade the cornfields in its millions. Curiously enough, although winged, in these migrations the bugs walk over the ground.

Although many of the Shield Bugs are green or brown, others are brightly coloured, red, blue or black; others like the Harlequin Bug are adorned with a variety of colours.

The Coreid bugs are related to the Pentatomids. They include the black Squash Bug (*Anasa tristis*) of North America, a pest on the squash vines, the Gum-tree Bug of Australia, and the Rice Bug (*Leptocorisa geniculatus*) of India and the Far East. They have elongated bodies and their colours are usually very close to those of the host plants.

The Fire Bugs, red with black spots, include the Cotton Stainers (*Dysdereus*) which stain the fibres of growing cotton. The Trinidad species of this genus has a migratory phase very like that of locusts.

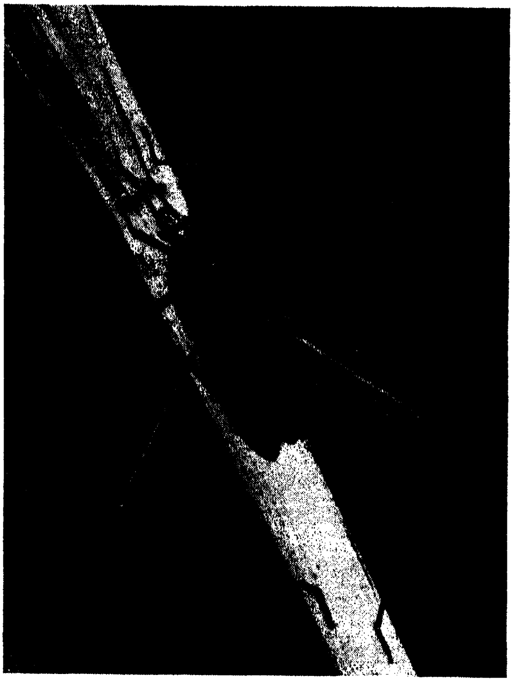
The Reduvoidea, or Assassin Bugs, are exceptional in being carnivorous. The Cone-nosed Bug, about an inch long, is known as the Big Bed-bug, or Kissing Bug, on account of its habit of biting the face of human beings. It is found in houses, especially in the southern and western United States. Other species of Cone-nosed bugs in Central and South America transmit a disease from man to man and from the armadillo to man. In Brazil they are known as "Babeiros" or Barbers, because of their habit of biting the face, and in other parts of South America as "Chinchas Voladoras", or Flying Bed-bugs.

Other Assassin Bugs are, however, more useful from the human standpoint. The species of *Phonoctonus*, of Africa, attack the Cotton Stainers, and strangely enough this Assassin Bug is red with black spots and in all ways remarkably similar to the Cotton Stainers on which it preys.

Other Assassin Bugs have grown to resemble mosquitoes, Daddy Long-legs, Stick Insects or even the Praying Mantis.

One of the last of the Land Bugs to be considered is the Bed Bug (*Cimex lectularius*), about one-fifth of an inch long, broad and flat, reddish-brown in colour and wingless. The usual habit is to hide in the cracks and crevices of houses, coming out at night to feed.

The Bed Bug, *Cimex lectularius*. This is difficult to deal with since it is capable of fasting for a year following a single meal, an obvious drawback to trying to defeat it by starvation. (Magnified 20 times.)

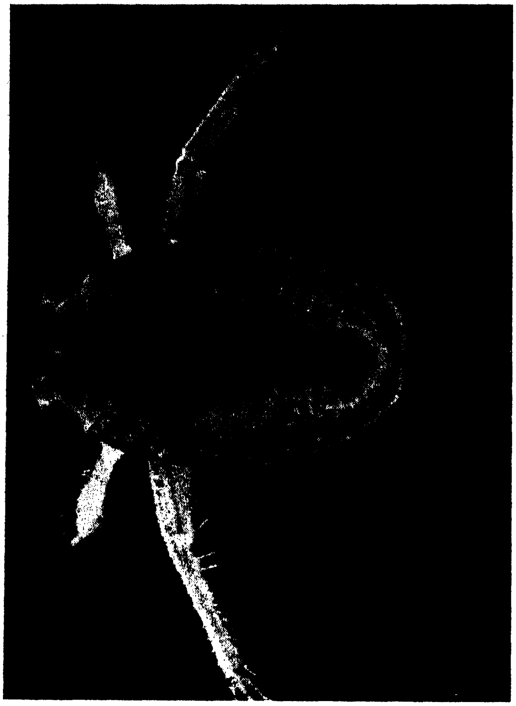


A Leaf-footed Bug. Some species of Coreids have a colour resemblance to the plant they live on and have developed leaf-like expansions on the legs, or even on the body.

Finally comes a group showing a transition to the Water Bugs. The Shore Bugs are dark-coloured, predatory and live on the sea-shore, in the salt marshes and in the mud bordering rivers and lakes. The Pond Skaters, on the other hand, actually live on the surface of the water. It is a paradox that the only marine bug should be included in the Land Bugs, but *Halobates*, the Sea Skater, living on the surface of the sea often hundreds of miles from land, belongs here.

Water Bugs

Apart from their aquatic habits these differ from the Land Bugs in two things: where wings are present, the fore wings are not stiff and horny near the base, and the antennae are concealed in cavities on the undersurface of the head.



Larva of a Water Boatman, *Corixa*. (Magnified 20 times.)

The largest of the Water Bugs is the Giant Fish-killer *(Lethocerus indicus)* of the East, ranging from India to Australia. It is four inches long, brownish in colour and oval in outline. Both young and adult are aquatic and feed on water-snails, insect larvae and fish. The adults are, however, strong flyers and, owing to the way they are attracted by lights and the manner in which they will swarm in numbers around electric lights, are known as Electric Light Bugs in the U.S., where two species, *Belostoma americana* and *Benacus griseus*, are commonly found.

Allied to the Fish-killer is the Water Scorpion, of smaller size but equally predatory habits. It is known in Australia as "Toe-biter" or "Needle-bug" from the habit of attacking bathers with its needle-like beak. Water Scorpions, about two inches long, have the first pair of legs shaped like those of the Praying Mantis, but without the spines, and from the tip of the abdomen extends backwards a siphon, or breathing tube. They live on the mud at the bottoms of streams, their brown colour harmonising closely with it, or among water-weeds.

The Notonectidae are mainly found in the temperate zone. It is difficult to say whether the British name, "Water Boatman", or the American, "Back Swimmers", is the more expressive. They look like miniature rowing-boats as they move gently along the surface of the water. On the other hand, their characteristic feature is that they swim on their backs. The body is oval, and the third pair of legs (the 'oars' of the 'boatman') are conspicuously longer than the rest. On the under side of the body is a long keel, with a trough on either side of it. When the insect submerges air is trapped in the troughs, by the aid of a series of hairs arranged over them. While under the water, therefore, the insect carries its own supply of air.

The food of the Water Boatmen, or Back Swimmers, consists mainly of mosquito and other fly larvae.

The Corixidae, or Water Crickets, are almost world-wide. They differ from all other Water Bugs in that the back of the head overlaps the thorax. They are small, oval, smooth and shining, rapid swimmers and, unlike the others, vegetarian. Their popular name refers to the ability of the males to produce a chirping sound. In some cases this is done by rubbing the front legs across the face, in others by drawing the edge of the front wing over a rasp situated on the back.

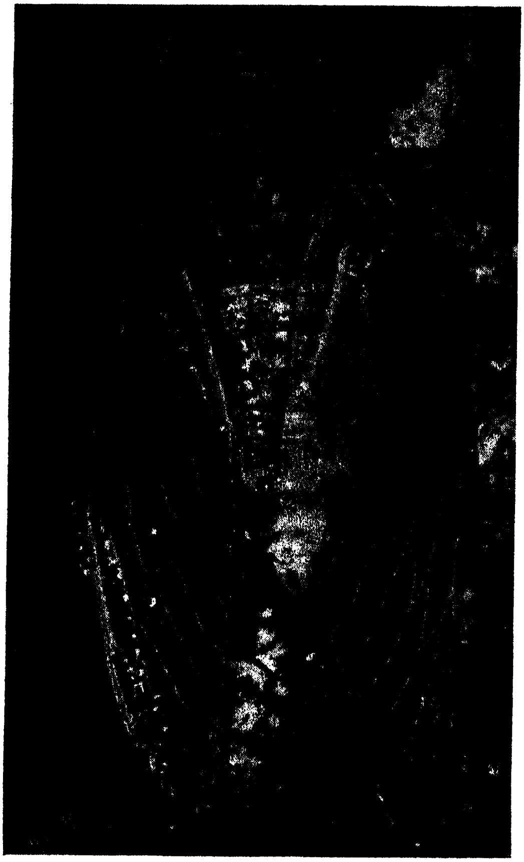
Sub-order Homoptera
(Cicadas, Frog-hoppers, Plant-lice, Scale Insects)

The most obvious way in which the Homoptera differ from the Heteroptera is that the wings, when at rest, are arranged in the manner of a roof over the body.

The male of a species of Cicada, showing at the side of the body the operculum covering the sound-producing organ.

A Cicada in the very act of hatching from the larva. The larva lives in the ground for 17 years, then crawls out and up on to a tree. There it clings until the skin of the back splits and the Cicada emerges.

Here the Cicada is almost out of the larva shell. Note that the wings are more developed at this stage.



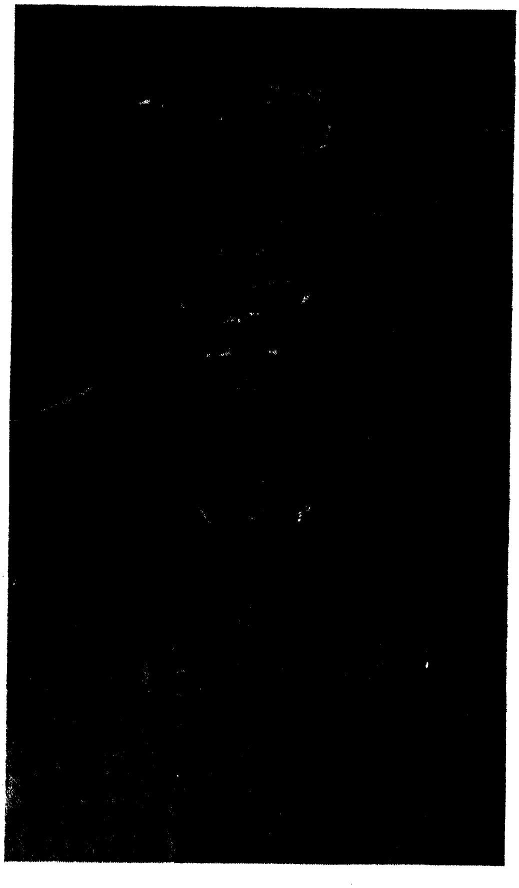
The Cicada shortly after leaving the larval shell. At this stage it remains clinging to the bark of the tree until its wings are fully developed.

The beautiful Cicadas contrast strongly with the usual idea of a bug. The body is stout, with broad head bearing at each side a large compound eye and with three simple eyes set in the centre. The thorax is short, but an extension of it projects backwards over the abdomen. The wings are large, glossy and nearly transparent, or finely coloured and somewhat opaque; together with the jewel-like eyes they impart a great beauty to the insect.

The female Cicada lays hers eggs in a twig, which she cuts open with her ovipositor. On hatching each grub drops to earth and buries itself, making a subterranean chamber, where it feeds by sucking juices from the roots. The underground life may last a long time, the longest known being that of the Seventeen-year Locust (*Tibicina septemdecim*). In this species 17 years elapse from the laying of the egg till the time when the larva emerges from the ground, climbs a bush or tree, and comes to rest. Then the larval skin splits and the mature Cicada emerges to live but a few days.

Only the male Cicadas sing, the noise being produced from a complicated organ at the base of the abdomen.

Frog-hoppers are probably familiar to everyone, both as the small masses of froth seen on plants and as the smaller, green or brown, hopping insects that spring out from the grass as they walk through it. Probably few people, however connect the two things, or realise that they represent two phases in the life-history of a single species.



Now that the Cicada's wings are fully developed the adult Cicada flies to a leaf, and will soon begin its new cycle of life.

The Frog-hopper has the short, broad head and prominent lateral eyes of the Cicada, and, although about a third of an inch long, has a faint resemblance to a frog in colour, in the manner in which it squats on a leaf, and in its leap. The larvae exude some of the sap they take in, mix with it a soapy secretion and blow bubbles of air into it, thus surrounding themselves with a protective froth. These gouts of froth are known variously as cuckoo-spit, frog-spit or toad-spit. An alternative name to Frog-hopper is the Spittle Insect.

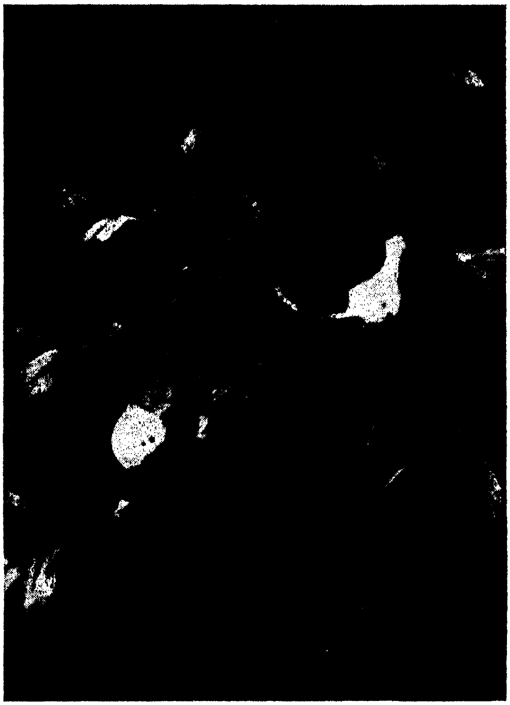
The larvae of certain species of Frog-hoppers live underground; but they still surround themselves with froth.

The minute Leaf-suckers, or Jumping Plant-lice, which look so like miniature Cicadas, do considerable damage to crops, especially to pear and apple. They are green or brown in colour, active, and combine flying with leaping, but are not capable of prolonged flight. These and the Snow-flies, Aphides and Scale Insects make up the remainder of the Hemiptera.

The Aphides, Plant-lice or Green-flies, deserve a special description on account of their methods of reproduction. This is given in Chapter 16.

The Scale Insects are remarkable for the way in which the females, after the second moult, lose their eyes and legs, and remain permanently fastened to the host-plant by their beaks. At the same time the body becomes transformed so that they look like scales on the stem and leaves of the plants—in fact, like part of the plant. In this condition, their activities are reduced to feeding and laying eggs. The males, on the other hand, remain fairly normal. The small, elongated body, about a quarter of an inch long, bears two slender antennae in front of the head, and a pair of very long, slender tails directed backwards from the tip of the abdomen. They have only one pair of wings and, being without mouth-parts, cannot feed. Their sole function is to fertilise the female.

Some Scale Insects are very harmful and include the San José Scale (*Aspidiotus perniciosus*), very destructive to apple, pear and other fruit trees in the U.S.A., and so-called because it was first introduced at San José, California; the Mussel Scale, a name given to various species of *Lepidosaphes* because they look like small mussel shells; the Mealy-bugs of the genus *Dactylopius*, pests of fruit trees, especially in greenhouses, and so-called because they cover themselves with a white powdery wax; and the Cottony Cushion or Fluted Scale (see page 284).



Cockoo-spit (*Philaeuus spumarius*); the frothy masses seen abundantly on foliage in spring are made by, and shelter, the larvae of the Frog-hopper.

Not all Scale Insects are completely harmful. *Dactylopius coccus*, of Mexico and Central America, living on cactus, is a source of the dye cochineal; and from *Carteria lacca*, of Northern India, we get lac, widely used in varnishes, dyes, sealing wax and other household products.

THE BIOLOGICAL CONTROL OF INSECTS

by

DR. C. H. CURRAN

Biological control of insects (and other animals and plants) is a natural process. It is that phase of the working of Nature by which one kind of animal (or plant), by preying upon another, keeps it under control. Undoubtedly, the most succinct definition of "biological control" is "the balance of Nature". Under natural conditions no animal or plant can dominate its surroundings for more than a relatively short period of time. In the case of plants, this period may extend over hundreds or thousands of years; the domination of any species is intimately connected with both soil and atmospheric conditions, the latter concerned chiefly with temperature. Animals are influenced by other factors. If they are plant feeders, their domination depends upon the abundance of suitable food, as in the case of the Bison and Buffalo, which are grazing animals and feed almost entirely upon grasses, or of the fox, which depends for its livelihood upon the presence of rats, mice, rabbits, birds and insects. In each case, the abundance of these creatures depends upon the amount of food available. The examples given should be applied in a broad sense and should not be considered as applicable to limited areas where man's activities may have an excessive influence upon natural conditions.

The biological control of insects may be compared to natural control only insofar as we are able to simulate natural control. We are very greatly handicapped in our efforts because many factors having to do with control of potential pests in any given area may be unknown to us and many years of research may be necessary before we become aware of their importance. As an example of such a situation, we might mention the case of the Gypsy Moth. This insect, which is guilty of only sporadic outbreaks of serious economic importance in Europe, became established in the State of Massachusetts in the United States in 1869, and by 1889 its depredations were cause for serious alarm. In limited areas where it had become well established, broad-leaved shade and forest trees were completely stripped of their foliage. The insect then began to spread rather rapidly until its range extended over most of the New England States. Efforts to control the pest by chemical means were wholly insufficient during the waning years of the 19th century, and by 1905 the threat of loss of enormous areas of forest products brought action by Federal and State governments that resulted in the organization of a Gypsy Moth Laboratory at Melrose Highlands, Massachusetts, for the study of the insect's biology.

The chief functions of the laboratory soon became the study of European enemies of the moth and their introduction into the United States. European entomologists were contacted and many of them gave enthusiastic cooperation. They reared the caterpillars and obtained parasites, and they observed, also, the kinds of insects that were predaceous upon them. Scores of different kinds of parasites were discovered, and a number of predators located. Of the latter, *Calosoma sycophanta*, one of the beautiful large ground beetles, was found to be the most important enemy, and the species was introduced into badly infested areas in New England. It became established and, because of the abundance of food, quickly increased in numbers. It spread rapidly in its own way, but the spread was aided by human transportation, to new areas. The chief characteristic that contributes to the value of *sycophanta* as an enemy of the Gypsy Moth (and other forest caterpillars) is its propensity for climbing trees. While most of its close relatives are content with life on the ground or on low plants, *sycophanta* spends the hours of darkness in running rapidly over high branches in search of food. During the day it buries itself under debris or in the soil.

Among the numerous parasities discovered was a fly known as *Compsilura concinnata*. This fly is widely distributed in Europe and was generally found to be the most dominant parasite of the Gypsy Moth. Many thousands were introduced into the United States, and the insect, finding conditions ideal, immediately established itself and avidly attacked the pest, which it was hoped it would control. Today, it is the most important natural enemy of the moth in America. Other parasites were introduced but few of them have become established or have given the relief that it was hoped they would bring. The introduction of *Compsilura* may not be an unmixed blessing. The fly has spread far beyond the range of the Gypsy Moth and it attacks the larvae of most of the native butterflies, which are not injurious and which are greatly admired by those who enjoy their presence. Many entomologists attribute the decline in abundance of the Monarch butterfly in eastern America to this insect. The Monarch is a beneficial insect, since its larvae feed upon milkweed (*Asclepius*) an undesired plant in pastures.

Biological control of the Gypsy Moth in America has not been a complete success. However, the parasites imported from its native lands have played a very important part in reducing its numbers and the rapidity of its spread. The lack of complete success may be attributed chiefly to the fact that many of its European parasites attack fewer than one percent. of the Gypsy Moth larvae (often only a small fraction of this), but because they are numerous in kinds, the total percentage destroyed is high. Obviously, it is not possible to introduce such creatures to new lands since many of them disperse rapidly, and the possibility of the two sexes coming together is remote. Again, we have the problem of suitable environment. The conditions under which insects live are strictly limited, and while we may bring insects into areas that seem identical with those to which they are native, there may be factors which are beyond the ken of our present knowledge. We know that some insects that are extremely important in the control of a certain pest must have alternate hosts, and if suitable hosts are not present, the parasite cannot live. Unfortunately, there may be very extreme time limits at which a possibly friendly parasite may attack an alternate host. This is especially true of those parasites that have two or three generations a year: the spring or fall

The caterpillars of many species of butterflies are gregarious. This photograph shows the devastating effect of groups of caterpillars of the Small Tortoiseshell on nettles.

The Colorado Beetle, *Leptinotarsa decemlineata*, has spread in the space of a century from the eastern slopes of the Rocky Mountains across North America and, crossing the Atlantic, has become a pest in Europe. Its many natural enemies include beetles, bugs, wasps and flies, yet even they only destroy one in five of the beetles. Clearly some other control is necessary. (Four times natural size.)

hosts may be the ones in which is built up the population that will attack the pest which it is desirable to destroy.

If biological control of the Gypsy Moth, the European corn borer, the Japanese beetle and some other transported pests have not been an unqualified success, there are many examples of perfect control. One of the earliest and most sensational of these has to do with the control of the cottony cushion, or fluted scale (*Icerya purchasi*), in California. The cottony cushion scale was originally introduced into California in plants imported from Australia. At the time it was first noted as a pest, its original home was not known, but entomologists soon discovered its origin. By 1886 its numbers had increased to such an extent that it threatened to wipe out the rapidly expanding and profitable citrus industry in the Pacific coast state, and Mr. A. Koebele, an entomologist of repute in California, was sent to Australia to locate parasites by the United States Department of Agriculture. Among the enemies of the scale in Australia was a small lady beetle, *Vedalia cardinalis*, and a small shipment of these was transported to America. Fortunately, the beetle found conditions much to its liking, but more important, it was ideally suited to the job it was hoped it would do. It had few, if any, natural enemies, and at the same time there were two or three generations a year to one for the scale. It is also important to note that both adults and larvae of this beetle fed upon the scale. The results following the establishment of the beetle in California were sensational: within a few years the scale insect was practically wiped out.

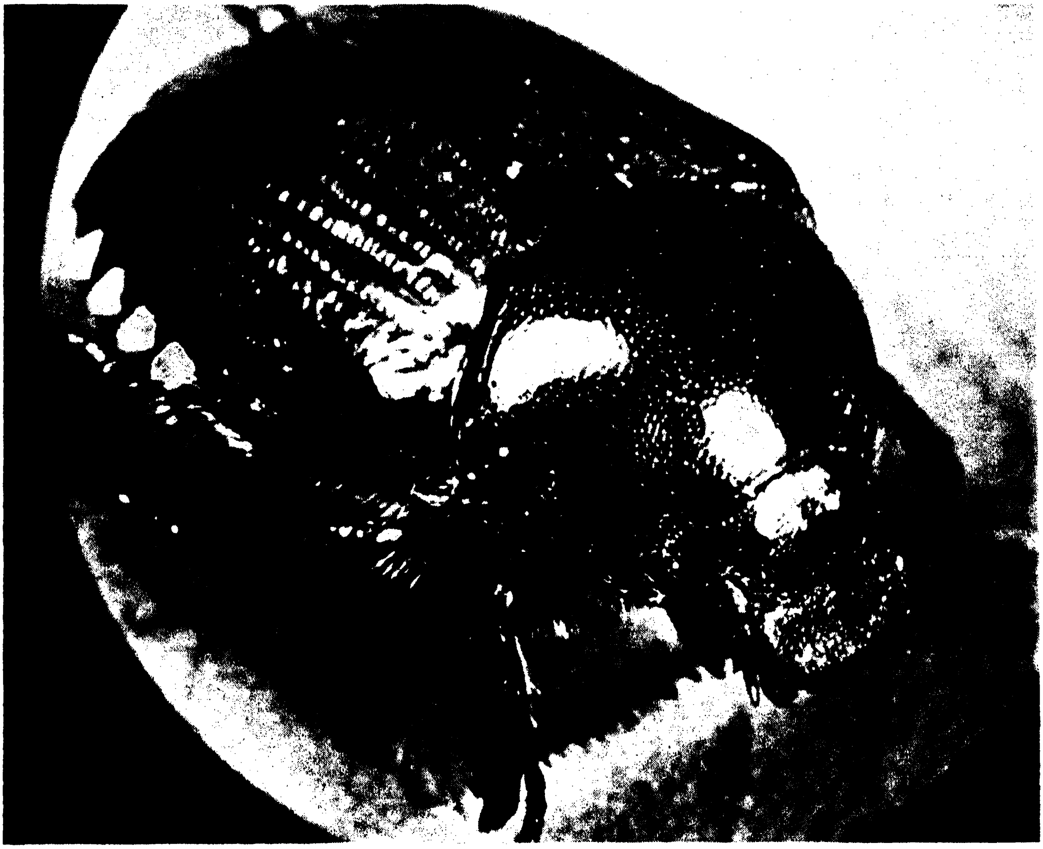
Cottony Cushion Scales (*Icerya purchasi*) on twigs.

This success was not an unmixed blessing because it engendered among the orchardists, farmers and others the idea that almost any pest could be controlled by the mere expediency of finding the proper parasite. They did not realize that many factors (which we shall later illuminate) enter into the successful introduction into any area of parasitic or predatory enemies of a pest. It was also an occurrence of extreme importance since it demonstrated beyond all reasonable doubt that certain pests could be controlled by the importation of pest insect enemies; and this one instance has provided the stimulus that has resulted in the wide study of natural or biological control which has proved so successful in many instances. We may add that *Vedalia* has since been introduced, with equal success, into many other parts of the world.

Among the many other notable successes by the biological method we must cite the control of the cocoanut moth (*Levuana iridescens*), the gregarious caterpillars of which stripped the leaves of cocoanuts in Fiji. A small fly (*Ptychomyia remota*) was discovered attacking a related moth in Malaysia, and a colony was introduced into Fiji, care being take to prevent the introduction of its parasites. The fly became firmly established by 1926 and within two years it had become established on adjacent islands; the moth has been kept under complete control.

Biological control of a different nature has been obtained in Australia. In this instance the control of a noxious plant has been obtained as a result of the introduction of an insect. During the past century cacti were introduced into

Australia with the idea of utilizing them for the raising of beneficial scale insects. At least four species of Opuntia (prickly pear) became serious pests and spread rapidly. At one time the spread covered about one million acres of grazing land per year. No success in its control was obtained until the discovery of *Cactoblastis cactorum* in Argentina. In its native haunts *Cactoblastis* was just an insect feeding on prickly pear, but when it was introduced into Australia, where it had no natural parasites, it became established and spread with amazing rapidity. Within a few years, the spread of the cacti had been halted and huge areas formerly infested were being reclaimed. These areas are increasing year by year, and there is good reason to believe that the plants will be kept under complete control and even exterminated over huge areas. *Cactoblastis* is not a complete success in South Africa because native parasites attack it.



The Japanese Beetle *(Popillia japonica)*, a destructive insect accidentally introduced into the United States.

The Hawaiian Sugar Planters Association has been one of the most active agencies in the world in the introduction of insects for the biological control of pests, and in most instances their efforts have met with great success. Their efforts were originally directed against cane insects, but the necessity of controlling other insect and plant pests soon led to an expansion of their program. Their efforts in seeking out beneficial parasites have been tireless: cane insects are well under control and much progress has been made in controlling the prickly lantana, a plant introduced as an ornamental plant about 1870. Of the 23 species of insects introduced to feed upon the pest shrub, eight have become established, each attacking the plant in a somewhat different way. The chief factors concerned with the successful introduction of an insect parasite are:

1. The ability of the parasite to establish itself in its new home because of climatic conditions.
2. The prevention of introduction of parasites from its native land.
3. The absence of parasites that will attack it in the region where it is introduced.
4. The presence of suitable alternate hosts for multiple-brooded parasites.
5. The natural development of the parasite in its new surroundings in order that its emergence in greatest numbers will coincide with the proper time for maximum parasitism of the host to be controlled.
6. The habits of the parasite. Some parasites disperse rapidly when released and the chance of mating is slight. Others remain close to the point of liberation.
7. The suitability of certain types of parasites to development and increase in numbers under laboratory conditions, such as *Trichogramma*, in which a population is built up on eggs of the flour moth, and other moths, and the parasites later released for control of the Oriental peach and codling moths.

While most biological control of insects has been concerned with the importation of parasites from foreign countries, and usually from a different continent, there are many examples of the utilization of local parasites, and once more we can draw upon California for an example. In the Rocky Mountain region many kinds of Lady Beetles (Coccinellidae), particularly *Hippodamia convergens*, hibernate in enormous numbers in selected spots. It has long been a practice to collect these and distribute them among agriculturists for the control of plant lice. A different development occurred during the study of control measures for the Japanese beetle in the eastern United States, with the discovery of milky disease of the beetle larvae. The origin of the disease is not known, but it has been studied and cultured and distributed to unaffected areas with considerable success in many instances.

It seems advisable to conclude this brief discussion of biological control of and by insects with the expression of an opinion that great new strides may be expected in the use of parasites to control both insect and plant pests. During the recent war, almost all research in this field was suspended, but great strides were made in speed of air travel. It seems possible that there may be many kinds of insects that could be transported and successfully established during their adult and egg-laying stages. It is quite conceivable that viable females of many kinds of parasites might be transported from one continent to another within two or three days, and that these insects would immediately seek out natural hosts. If this should happen, there would be no need to seek mates. Often, a single fertile fly or parasitic wasp might parasitize two to six hundred hosts and thus produce a reservoir for the next year. Actually, it might be very difficult to secure even a hundred specimens of the pupal stage (the usual stage for introduction) in a single season. Therefore, a half-dozen fertile females might well be more efficient than a thousand or more pupae.

Rapid transportation will do much more. It will enable the transfer of pupae and larvae to any part of the world within a few days, and refrigeration, or temperature control, to insure the non-hatching of parasites until the proper time, will be of little importance. Lack of temperature control has, in the past, been the cause of enormous casualties among the parasites being so hopefully introduced, often after extremely high costs of collecting and careful nursing pending suitable transportation.

CHAPTER XIX

THE INSECTS III

THE SUB-CLASS ENDOPTERYGOTA

This contains those insects which in their life-history pass through a complete metamorphosis (egg, larva, pupa, adult) with a resting pupa (or chrysalis). Also, the wings are developed internally

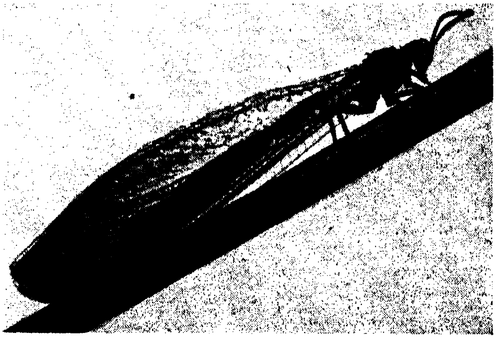
Order Neuroptera
(Alder-flies, Ant-lions, Lace-wings)

ALL members of the Neuroptera agree in having biting jaws and, with occasional exceptions, four nearly similar wings, with complicated veining. Their wings, when at rest, are held over the abdomen like the sides of a roof.

In England the Alder-fly, best known to anglers, is found along the banks of the quiet streams. Less than an inch long, it is brownish, of clumsy build with black-veined wings. The larva is aquatic and strongly predaceous, breathing by means of filamentous outgrowths from the sides of the body. On reaching maturity, it leaves the water and burrows into the soil to pupate. In America the Dobson-fly (*Corydalls cornuta*), also known as the crawler or hellgramite, is found in similar situations and has the same life-history. The aquatic larva, which stage lasts for three years, is used as bait.

Ant-lions. Found throughout most temperate and tropical regions, the adult Ant-lions closely resemble Dragon-flies, for which they are often mistaken, but, like most members of the Neuroptera, except Dragon-flies, the wings are folded when at rest. Their bodies are not so long and so markedly narrow as those of Dragon-flies, however. Ther larva has a stout, oval body with a flattened head bearing a pair of enormous jaws. Its habit is to dig a pit in sand and to lie in wait at the bottom for other insects.

Ascalaphus-flies. These are closely-related to the Ant-lions, which they resemble except that the adults have long club-shaped antennae, giving them a butterfly-like appearance. They are distributed throughout tropical countries, and the warmer parts of the temperate zone.



An adult Ant-lion resting on a grass stem.

Lace-wings. The difference between the delightfully-built adult Ant-lion and its sombre, predatory larva is more strongly emphasized in the case of the Lace-wing fly. The adult might fittingly be called a fairy fly. About an inch long it is delicacy personified, both in build and colouring. The slender body is a delicate green, the fine, gauzy wings of the same hue, and on the head are a pair of enormous golden eyes. The larva, on the other hand, is greyish and inconspicuous, and has the same build and the same powerful jaws as the Ant-lion larva. It spends its time wandering about over plants devouring quantities of aphides, thrips and scale-insects. What happens if two larvae meet is not recorded, but can be imagined from the action of the female when laying her eggs. The eggs are laid on the undersides of leaves in groups, but each egg is poised at the top of a silken stalk (see page 253). If this were not done

The Death's Head Moth *(Acherontia atropos)*. This moth has been credited with robbing bee hives for the honey, but a doubt is now cast on the truth of this.

it is highly probable that the first larva to hatch out would quickly devour the remaining eggs.

Order Trichoptera
(Caddis-flies)

Caddis-flies, found throughout the world, have many features in common with some of the less specialised moths. The adult is not well-known, being of a retiring disposition, although it can be seen in the neighbourhood of almost any pond or stream. Both body and wings are covered with fine hairs, the front wings being long and narrow, the hind wings much larger and folded fan-wise over the body when at rest. The colour is a mottled grey or brown. The larvae, or Caddis-worms, are known to all pond-hunters. They are aquatic and, in most species, vegetarian. They build characteristic houses of small stones, pieces of stick or leaf, indeed of almost any material available, glued together with saliva to form a tube, closed at one end, and lined with silk. The few carnivorous species spin a funnel of silk for catching their prey.

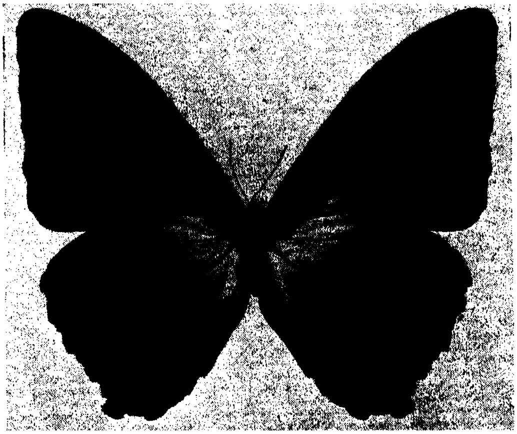
When ready to pupate, the Caddis-worm seals the free end of its tube, and after the resting period leaves its home and crawls up the stem of a water plant or, in some species, swims to the surface, where the mature insect emerges.

Order Lepidoptera
(Butterflies and Moths)

It is the practice to divide this order into two, the Microlepidoptera, including all the small moths, and the Macrolepidoptera, or the large moths and the butterflies. The distinction between these two groups is not, however, as simple as this statement might make it appear, but it is not necessary to go into greater detail. Broadly speaking we may distinguish between butterflies and moths by the following characters. A butterfly is active by day, resting at night, folds its wings together over its back when at rest and has slender antennae ending in a knob or club. A moth is mainly active at night, keeps its wings flat over its back when at rest and has antennae that are usually feathered, or if just straight and simple are never clubbed at the ends. Although there are occasional exceptions to these rules, they act as a rough but fairly reliable guide.

It is not possible here to deal adequately with the Lepidoptera, in view of the very great number of species known. There are, for example, more than 2,500 species in the British Isles alone, and 10,000 species in the U.S.A. It will be sufficient therefore to deal in general terms with their structure and habits. In addition, they will serve to illustrate two biological principles: the variations found within a species, and the devices used for escaping from enemies.

The Lepidoptera differ from all other insects in having the wings covered with scales, actually modified hairs arranged like tiles on a roof.



One of the large metallic blue butterflies *(Morpho hecuba)*, from Brazil, whose wings are used in ornamental jewellery. (One half natural size.)

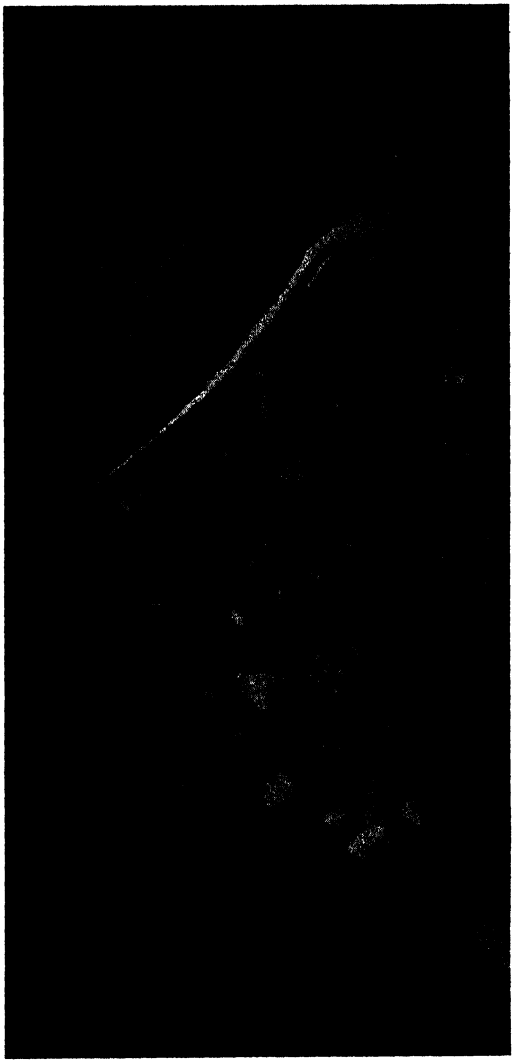
They vary much in shape, and their pigments provide the colouring, often so vivid, with which we are familiar. A few species of both moths and butterflies have no scales, and there are some species which have no wings at all.

The adults all have large compound eyes, but the caterpillars have only simple eyes, or ocelli. As in all insects there is no focussing apparatus and it can probably never be known with precision what butterflies see, but there is experimental evidence to show that they are short-sighted, able to distinguish shapes and colours at close quarters only. In addition they can also distinguish between different colours. For example, one species tested showed a strong preference for purple flowers, a reduced preference for red and very little for white. Generally speaking, the evidence suggests that the male first recognises the female by sight.

Moths, flying mainly at night, have a mechanism in their eyes for altering the pigment around the cones, which acts in the same way as the human iris, admitting more or less light as the occasion demands.

The antennae perform a number of functions. In the first place they act as balancing organs while the insect is in flight. In addition they combine the senses of smell and touch. Each is covered with minute pits, containing one or more bristles, in which these senses are lodged.

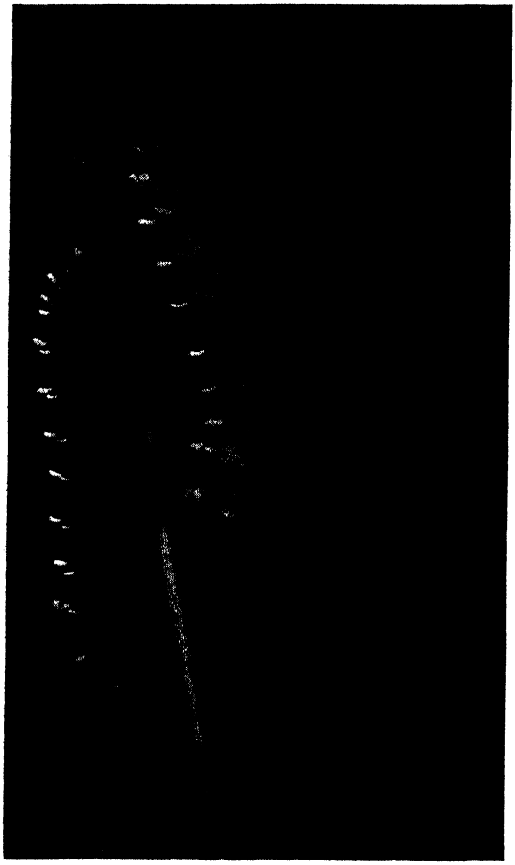
So that they may beat in unison, the wings of a moth are fastened together by a spike on the base of the hind-wing which fits into a catch on the fore-wing.



A caterpillar of the Swallowtail Butterfly (*Papilio machaon*) in the act of pupating. The caterpillar has anchored itself to a stem by a pad of silk at the tip of the abdomen and constructed a loop of silk to support the front part of the body. The fore part of the body is already undergoing metamorphosis.

Both these senses are very keen, and on this depends the collector's trick of exposing a freshly-emerged female to attract the males, some of whom have been known to come from long distances. Another trick is to smear the bark of a tree with a mixture of stale beer and molasses to achieve the same end.

Hearing is through a pair of slits, one on each side of the body, near the thorax, which open



Caterpillars of the Cecropia Moth of North America.

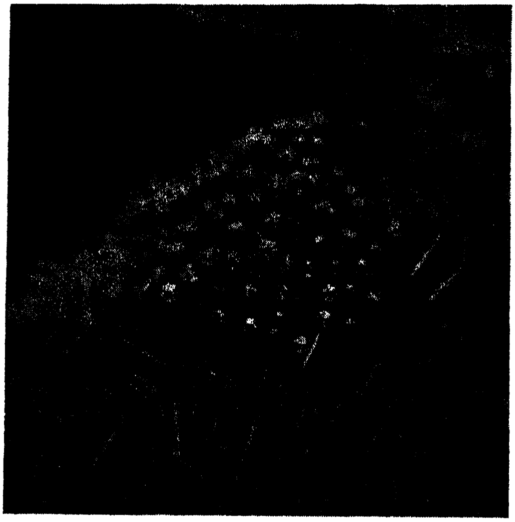
into cavities across which a thin membrane is stretched.

The life-history consists of four stages: the egg, larva, chrysalis and adult. The shape of the eggs varies, but all are beautifully, though microscopically, sculptured on the surface. Each has a minute opening at the top, the micropyle. Through this the egg is fertilised before it leaves the female's body. Afterwards, it serves to allow air to reach the developing embryo. A considerable quantity of yolk is provided inside for food. When the young caterpillar is ready to hatch, it eats a hole in the egg-shell and crawls out.

All Lepidopterous eggs are laid on plants, but the young caterpillars usually feed on certain kinds of plants only, and many caterpillars will die if the correct plant is not available to them. Yet the female butterfly or moth, although it feeds on other things, such as the nectar or flowers or, in rare cases, decayed fruit, animal droppings or perspiration, will, as a rule, by a wonderful instinct, lay its eggs on the plant on which the caterpillar will want to feed. Perhaps this is not so remarkable as at first it appears, for the caterpillar and the butterfly are not two different animals, but two stages in the life of one animal.

The caterpillar has a head corresponding to that of the adult, and a body consisting of thirteen segments, the first three corresponding to the adult thorax, and the remaining ten to the abdomen. The first three segments (i.e. the thorax) bear each a pair of true legs. Some of the abdominal segments, usually the third to the sixth, are equipped with pairs of pro-legs or false-legs. These are soft and fleshy, without joints and end in a contractile pad surrounded by a ring of minute hooks. Doubtless the pro-legs represent relics of an ancestral condition, recalling that in the early insects when each segment of the body bore a pair of simple legs, as *Peripatus* does to-day (see Chapter 15).

The head bears a pair of small, three-jointed antennae, with simple eyes instead of the conspicuous compound eyes of the adult, and biting mouth-parts. The salivary glands have been converted into silk-producing organs.



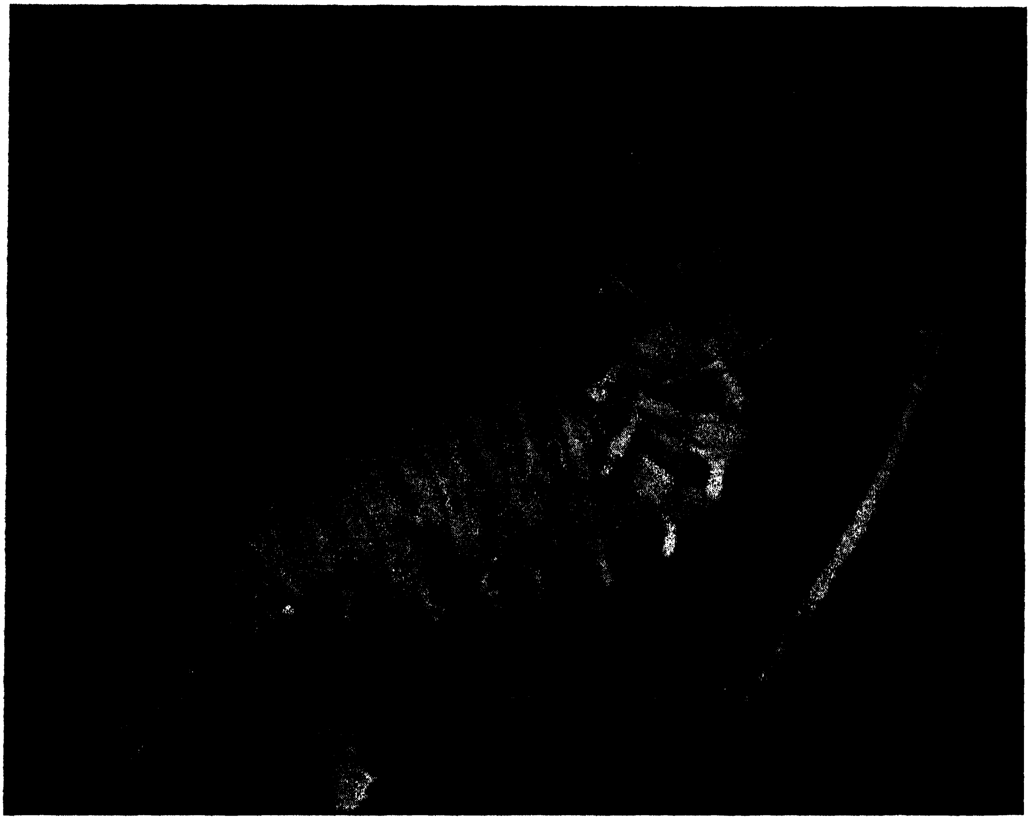
Egg clusters of the Butterfly *Vanessa urticae* on the underside of a leaf.

On the right is an enlarged view of the Cecropia Moth caterpillar. In the front can be seen three pairs of true legs; behind are some of the pro-legs.

There is a considerable difference in the appearance of the newly-hatched and the fully-grown caterpillar, which makes their identification difficult except by the experienced naturalist. As the caterpillars feed and grow they moult, usually four times, and at each moult the new cuticle shows differences in colour pattern, and the shape and number of the setae. Finally another moult occurs, this time resulting in the appearance of the chrysalis. This is known as the metamorphosis, a process in which the most remarkable and fundamental changes take place in the organisation of the body. The chrysalis, enclosed in a tough, horny cuticle, shows on the surface the various parts of the adult's body. The large compound eyes can be seen in outline, as well as the legs and wings. This is the resting stage when, although the spiracles are open and breathing goes on, the insect neither feeds nor moves about.

There are several conditions in which the chrysalis may be found: either enclosed in a silken cocoon, or hanging head downwards attached by the tip of the abdomen, or attached by the tip of the abdomen and supported head upwards by a girdle of silk. In the last two, it is attached by a group of hooks, called a cremaster, to a pad of silk spun by the larva before the change takes place.

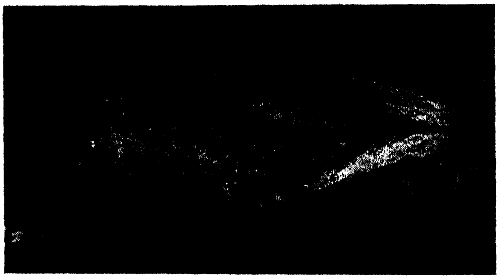
At the metamorphosis, an interesting process of death and re-growth takes place. Most of the larval parts die, only a few persist to become functional organs in the adult. All the other organs arise from groups of reserve cells, known as imaginal buds, which have been present in the larva all the time.



The Cecropia Moth caterpillar in the act of spinning the cocoon. The head of the caterpillar moves back and forth like a shuttle while weaving the silken strands about its body.

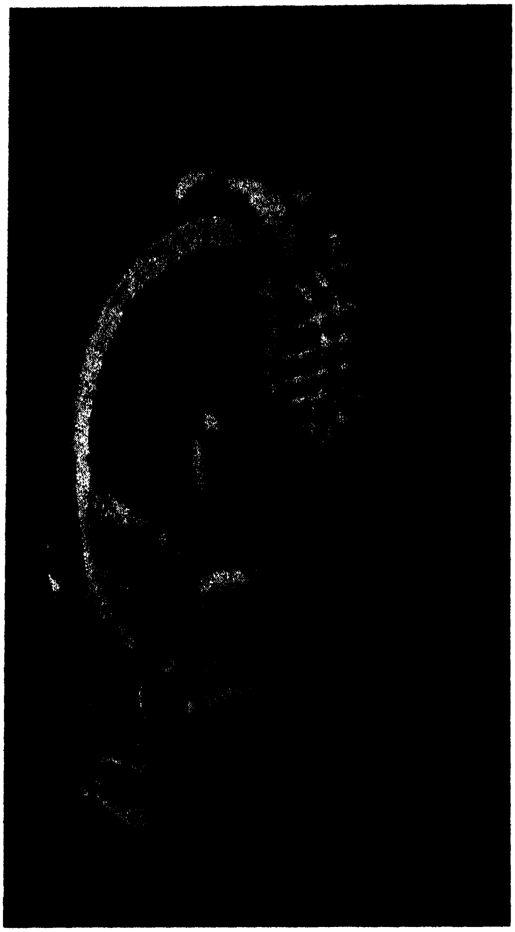
The pupal life lasts for some three weeks or so, varying according to the temperature. Some species, however, pass the winter in this state. At the end of the time, the pupal skin splits behind the head and the insect begins to crawl out, drawing its wings, antennae and legs out carefully. Next it moves to a position nearby where its wings can hang downwards. At first these are only about a tenth of their full size, crumpled, soft and delicate. Blood is forced into them and they expand, and after an hour or two, according to the species, become dry and hard, and the insect is ready for its first flight.

Those species living in the temperate zones must habitually meet the rigours of winter, even to the point of being frozen solid. This they may do in the egg, larva, pupa or adult stage according to the species. Some pupae have been taken from the frozen earth so brittle that they broke in two on being dropped, yet, it may be presumed, they would have revived and continued to live in the normal way had they not been disturbed. Similarly, others can be submerged in water for greater or shorter periods of time and still pass unscathed to the following spring. An interesting adaptation is found in certain species which hibernate on the leaves of deciduous trees. Against the time when the



Cocoon of Cecropia Moth.

Here the Cecropia Moth cocoon has been cut open, exposing the pupa. The pupa is encased in the cocoon which gives it protection from the severe weather during the cold winter months. The moth hatches in the spring.



A newly emerged Cecropia Moth clings to a stem until its wings becomes strong enough to carry it about.

leaves would fall, the larva of such a species secures the leaf it is on to the stem with threads of silk.

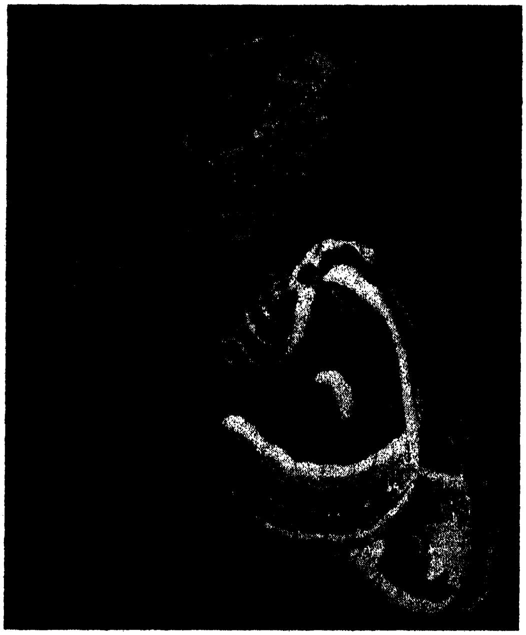
In the hot dry regions of North Africa, and in other desert regions, the moths and butterflies aestivate. That is, they remain dormant during the intensely hot summer, and are, as a consequence, seen only in spring and again in autumn. Another method of avoiding seasons of trying weather, the intense cold of winter or the intense heat of summer, is by migration. Although this is known to occur it is, nevertheless, rare among Lepidoptera. Local migrations do occur, together with some occasional widespread movements, among which is the most outstanding case of the Monarch butterfly of North America.

The mouth-parts of adult Lepidoptera have been converted into a proboscis, with a pair of palps at the base. The proboscis consists of two tubes which lie close together throughout their length to form a third or false-tube. The latter is the channel through which food is taken in, the former two tubes containing the muscles for coiling and uncoiling the proboscis, and the nerves serving the very sensitive papillae at the end of the proboscis. Since the proboscis is often more than twice the length of the insect's body, and since the nectar is often situated deep down in the long, tube-shaped corolla of a flower, it is clear that the tip of this organ must be the main guide in finding food, and must be highly sensitive for purposes of both touch and taste.

When not in use, the proboscis is carried coiled like a watch spring against the undersurface of the head.

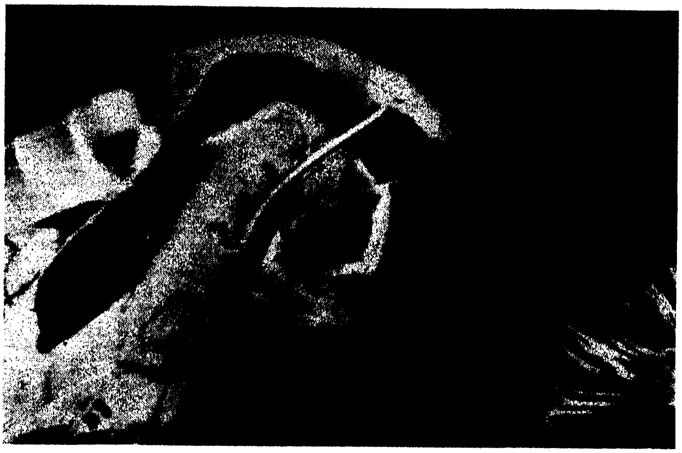
In a few species of moths the mouth-parts are vestigial, the adult insect taking no food but relying upon that stored up during the larval stage.

Certain of the more primitive moths have, in addition to the proboscis and palps, a second



A newly born female Cecropia Moth that has just crawled from its cocoon.

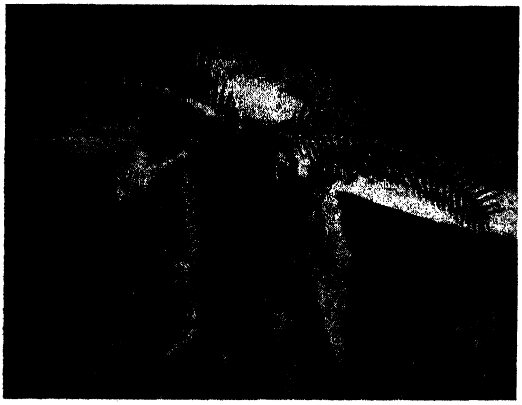
pair of palps, or, in rare cases, a pair of jaws. There is an evolutionary significance in this, as it serves to show that, much as the Lepidoptera have departed from the general insect plan, they have descended from a stock which formerly had the same kind of mouth-parts as other insects.



A North American Hawk Moth. All Hawk Moths have long tongues for probing the equally long tubular flowers in search of nectar.

The production of nectar by flowers and the use of it for food by butterflies and moths is linked, as in all cases where insects visit flowers, with pollination. There are many striking examples of the way in which both plant and insect, either in structure or behaviour, have become adapted to this end, but none is more remarkable than that of the Yucca, a liliaceous plant of America, and the Yucca-moths, of the genus *Pronuba*. The best-known species is a small silvery moth, *Pronuba yuccasella*, about half an inch long, found in the south-eastern states of the U.S.A. The female moth collects the pollen from the anthers of the Yucca, fashions it into a ball with her mouth-parts and, carrying it on the undersurface of her head, deposits it on the stigma. Thus she ensures the fertilization of the ovules and the development of the seed-pods. She then proceeds to pierce the pistil with her ovipositor—an organ not usually present in moths—and lays her eggs among the ovules. As the seeds develop the larvae hatch out and proceed to feed on them.

Although the habit of migration is not generally associated with such a fragile insect, investigations by Dr. C. B. Williams, the British entomologist, over a period of about 20 years have proved that many species of moths and butterflies do migrate. These movements, though seasonal in many places and in distinct direc-



Front view of a Cecropia Moth, showing the head and the fern-like antennae.

Scales from a butterfly's wing.

Caterpillar of the Puss Moth in characteristic pose.

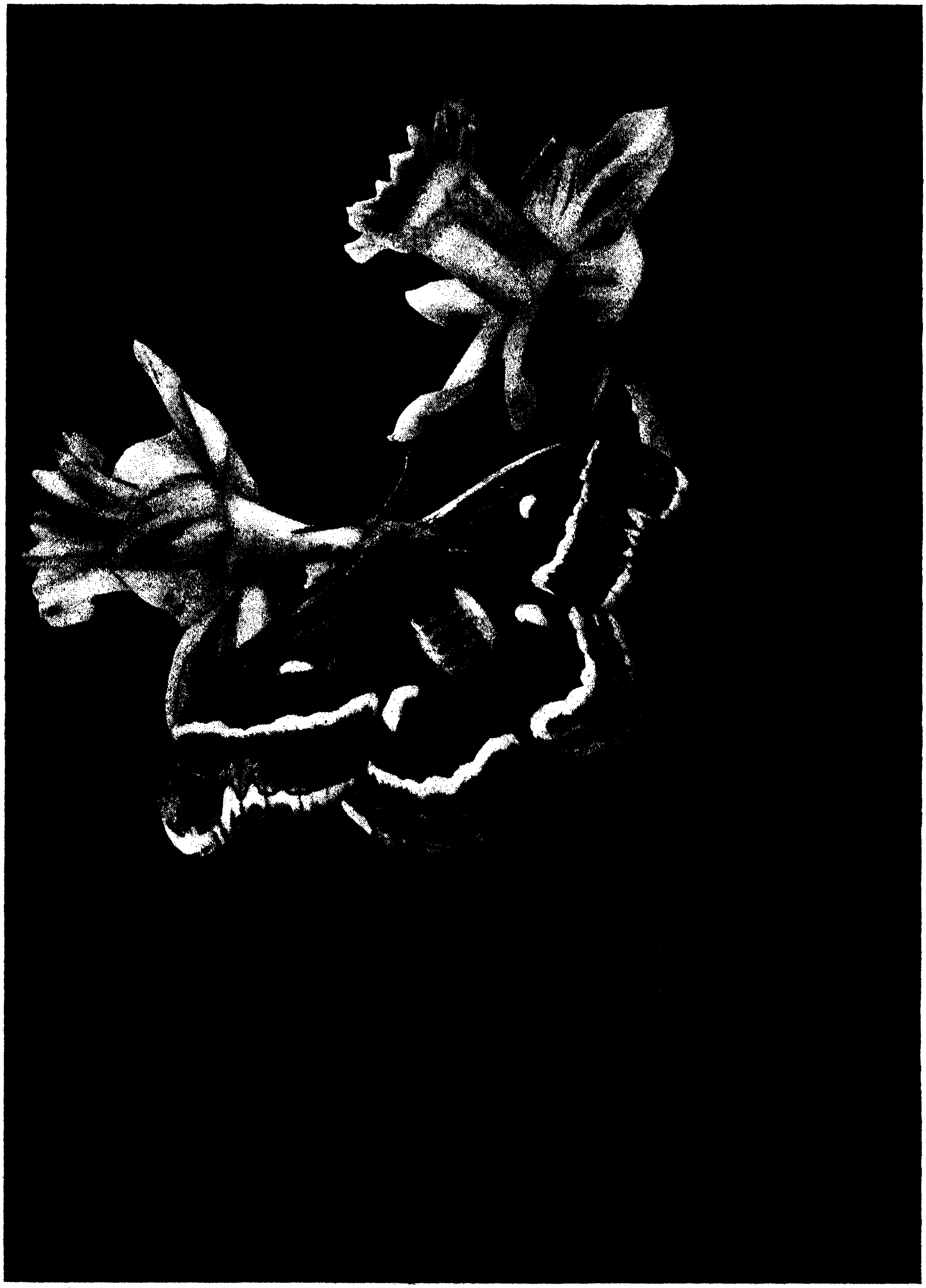
tions, do not entail the long distances such as are covered by birds.

There is, however, one outstanding example, that of the Monarch Butterfly (*Danaus plexippus*) a species widely distributed throughout North, Central and South America. This handsome butterfly has wings four or five inches across, is deep orange with black and white patterns. Another of its popular names, the Milkweed Butterfly derives from the plant upon which the female lays her eggs and which later forms the food for the young caterpillars. These are conspicuous with their transverse bands of yellow and black as they feed voraciously on the Milkweed and mature rapidly. The pupal stage, which lasts from five to fifteen days according to climatic conditions, is reached in about a month. The butterfly itself lives ten or eleven months and does not appear to have any natural enemies. There are usually two or more broods during the course of the spring and summer and it is the butterflies of the later broods which towards the early autumn begin to assemble for their great journey southward.

Monarch butterflies migrate northwards in the spring, travelling far into Canada, and in the autumn enormous numbers of them collect together in great clouds, flying massed in a stream across the sky. Not only do they travel during the day but quite often are seen to continue their journey through the night flying, sometimes at a great height, towards their winter quarters. Although the southward journey is a mass movement and the butterflies roost together in tightly packed companies in the branches of the trees, with the coming of spring these groups break up, the northward migration being usually made singly.

Vast numbers of Monarch butterflies congregate in California during the autumn, where for 600 or more miles along the coast they spend the winter months. Their favourite resting places are clumps of evergreen trees, usually Montery pines, cypresses and eucalyptus situate along a coastal belt less than a mile wide. Some of these trees are visited regularly each year by

A "Clearwing" Saturnid butterfly (*Callithaera menander*) from South America. The wings are transparent, so that objects can be seen clearly through them.



The Cecropia Moth of North America. Its size can be judged by comparison with the daffodil blooms.

A close-up of the face of the "owl" butterfly showing the large compound eyes, antennae and coiled tongue.

succeeding generations of butterflies. On arrival they settle on the undersides of the branches, always 20 feet or more above the ground, hanging side by side, so closely packed together that the foliage is almost obscured. The winter is not spent in a complete state of hibernation, however, for on a warm day it is a common sight to see numbers of them on the wing. Mating does not generally occur during this period as only the males are sexually mature in the autumn; the ovaries of the females do not function until the return northwards begins.

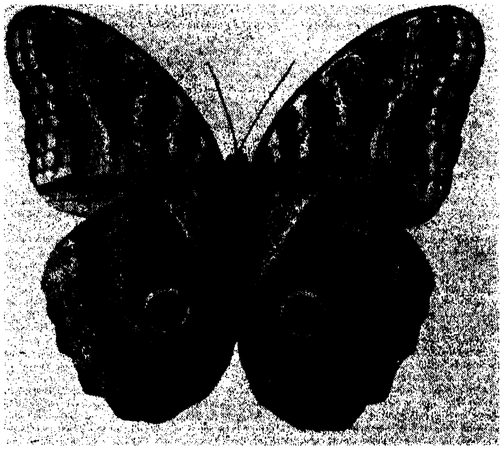
The great distances Monarch butterflies are able to cover is evidenced by the widely separated areas in which they now appear to be established. They are resident in the Hawaiian Islands and have spread to the Carolines, Marquesas, New Zealand, Australia and the Dutch East Indies, Bermuda, Cape Verde Islands, Canaries and the Azores. Specimens have been found even in the British Isles and although many of these may have crossed the Atlantic in ships there is evidence that some at least have made the crossing unaided.

PROTECTIVE COLORATION IN INSECTS

by

PROFESSOR G. D. HALE CARPENTER

The great numbers and small size of insects render them specially vulnerable to attack by the larger predators: how then do they escape destruction? The first principle for safety is to avoid being seen, and the simplest way to effect this is to take cover. Thus great numbers of defenceless insects live among dead leaves, in decaying vegetation, within the substance of plants, or even underground. It must be realised however that such methods are of little avail against their own kind, which seek them out by other senses than sight. Such concealment may only be utilised during daylight, and a good example is afforded by the black ground beetles, so common under stones, and of nocturnal habits. The next step to physical invisibility is to take such advantage of the visual processes of the



One of the "owl" butterflies (*Caligo* sp.) from South America.

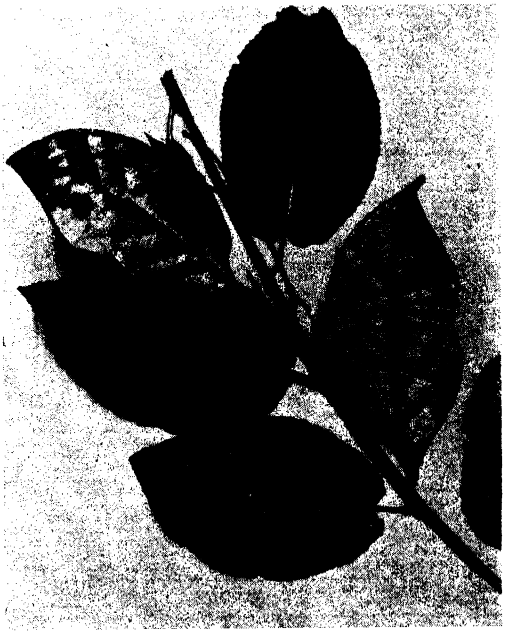
enemy as to appear to be invisible by merging into the surroundings. Visibility depends upon several factors, of which colour comes to mind first, and will be first discussed.

Concealing coloration is now generally known as Cryptic, and this crypsis is either general or special, according to whether it produces merely a general effect in harmony with the environment as a whole, or whether there is a detailed resemblance to a particular part of the surroundings. An earth-coloured grasshopper, or green insect among grass, are familiar examples of general crypsis, and, being used in defence, it is termed general Procrypsis, and is exceedingly common. If such coloration is primarily to enable an insect to secure its prey it is termed Anticrypsis, but examples are not easily found, as with insects there is always the defensive aspect to be considered. A certain genus of predaceous sucking bugs, *Mononyx*, which, of earth colour, flattened, and sluggish, sit on damp earth and seize small butterflies when they alight to drink the moisture, may be given as an example of general anticrypsis.

Special Procrypsis has always aroused admiration by the perfection of its detailed resemblance to a stick, stone, dead leaf, or bird-dropping. A. R. Wallace recorded long ago how natives of the Malaysian Archipelago brought to him a stick insect apparently covered with real moss. The famous 'dead-leaf' butterflies (*Kallima*) bear on the undersurface of the wings, which in colour suggest a dead leaf, faithful reproductions of small patches of fungus growth, or of the damage caused by small insects. Some leaf-like grasshoppers represent by the jagged outline of the wing-covers a leaf from which a piece has been bitten out.

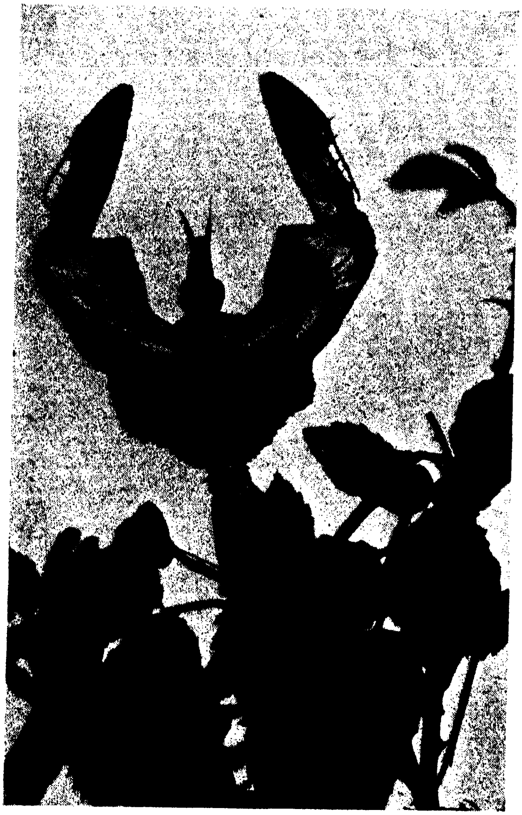
Special Anticrypsis is notoriously illustrated by one of the predatory Mantids which, with expansions of the integument of pink colour on limbs and body, looks like flowers and actually attracts the insects on which it preys.

Cryptic Coloration is commonly fixed for any individual, but among caterpillars and spiders an individual may change its colour in accordance with a change in habit or environment: this is known as Variable Crypsis. A milk-white spider on a white flower, if transferred to a yellow flower, assumes a yellow colour in its new haunt. Variable Coloration may also be shown in the species, rather than the individual, as when a species appears in two alternating forms in tropical countries: one, in the dry hot season when insect life is scarce and danger from predators greatest, is cryptic, while the other, in the wet season, may be quite conspicuous or at least less cryptic, at the time when there is a large choice for a predator among teeming masses of insects. The same species may thus appear in two Seasonal Forms.



The Indian Leaf Butterfly (*Kallima*) looks very like a dried leaf when at rest with its wings folded.

Crypsis is an affair of life, and attitude, movements, and habits all play their part in accentuating resemblance brought about by the shape and colour. But coloration in itself, i.e. the harmony in tint between an object and its surroundings, is not the only factor in concealment. A solid object throws a shadow, and we judge a stick or stone to be solid by reason of the darker tint of its lower parts thrown into shadow by the projecting upper parts. The cylindrical body of a caterpillar thus betrays itself, but in nature we find this is overcome by lighter tint of the lower parts which counterbalances the effect of shadow. This is Thayer's principle of Countershading. Sharpness of outline, as exemplified by the wings of a moth outspread, is exceedingly revealing, and is overcome by strongly contrasted patches of colour of which some of the elements correspond with the background while others, in contrast with it, mask the real outline. This is Cott's principle of Differential Blending. Again, any single area of one colour has a definite shape by which it may be recognised: if this unicolorous area is cut up into irregular areas by patches of conspicuous brightness the shape is masked, and the eye is caught by the bright patches which do not suggest the shape of the desired prey. This is Disruptive Coloration (Cott). All these factors produce Cryptic insects.



A mantis, known as the "Diabolical Spectre" *(Idolium diabolicum)*, from Mozambique, poised ready to capture a butterfly. The leaf-like extensions of the legs and body render it inconspicuous against a leafy background.

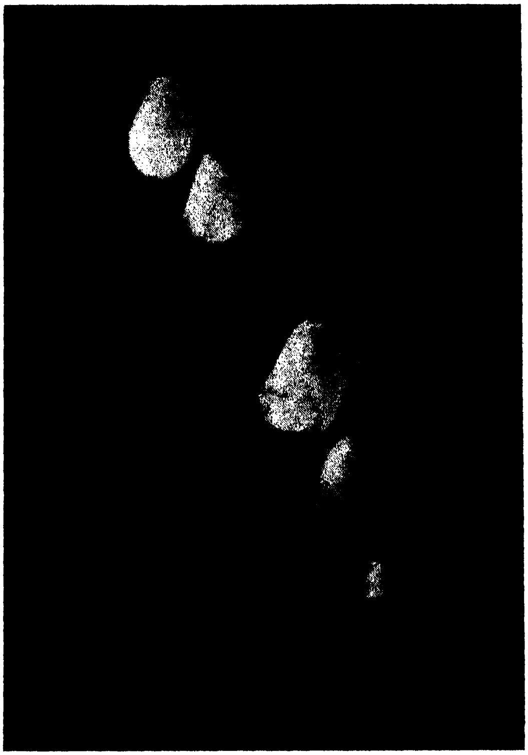
But there is another class, of opposite type, conspicuous, with bright colours easily distinguished, and with habits which reveal them all the more. It has been found that, while cryptic insects are highly edible, these conspicuous species are not readily eaten. The conspicuous coloration is associated with the power to emit acrid juices, or to sting, or the presence of irritating hairs or spines, and is therefore known as Warning, or Aposematic coloration. Its object is to proclaim to an enemy that the wearer is objectionable. Consequently, aposematic coloration is easily recognisable. But the enemy has to learn, and a certain mortality must result from the process. Thus an aposematic insect is tough and can resist a good deal of rough handling, so that when released after the enemy has, perhaps, experienced its evil smell or sting, it will be little damaged. Just as cryptic insects have habits accentuating their appearance, so do aposematic species which are sluggish and of bold demeanour.

Since the enemy, in learning what to avoid, destroys a certain number of insects bearing any particular aposematic pattern, each pattern loses by this process a certain percentage which may be called X. Now if each pattern is borne by only one species then X loss falls on each species. But if several species all had the same pattern then the X loss of that pattern falls upon a number of species, each of which loses only a fraction of X, the value of that fraction depending upon the number of species sharing in this Common Warning, or Synaposematic, Coloration. This has, in fact, happened in nature, and the banded black and yellow of wasps of many different kinds, with caterpillars such as that of the Cinnabar moth and beetles, such as some of the Burying Beetles, is an example of Synaposematic Coloration. This association for mutual advantage, having been first described by F. Müller, is very widely used and has in the past been termed Müllerian Mimicry, but the term Mimicry should be reserved for the third class of protective coloration involving a deceptive appearance.

An insect of the more edible type, in superficial appearance only, resembles an aposematic species to such an extent that it may be mistaken for it by a predator and left alone, in the presence of less dubious morsels. This phenomenon of False Warning Colours, first described by Bates, is known as Batesian Mimicry: the coloration is technically termed Pseudaposematic.

The chief point about mimicry is that it deceives the artist, not the anatomist. The mimic must keep the enemy at a distance, for it has neither the toughness to enable it to stand examination, nor any defence if the enemy comes to close quarters. Thus there is no need for anatomical resemblance. The likeness to its 'model' may be produced by different means, but the end result is the same. It will be understood that as mimicry involves deception, it cannot be employed very frequently, for then the deception would defeat its own object. If, among a number of yellow-spotted black insects one half are not really objectionable, it would pay a predator to catch and examine all, and the defenceless mimics would be destroyed. But if only one per cent. are without objectionable qualities they will be unlikely to be discovered. Thus Batesian mimicry is rare. It is found among insects and their allies of very many kinds, and may be best illustrated by spiders which resemble ants. Anatomically a spider is very widely different from an ant: it has only two parts, whereas an ant has three. But there is a superficial constriction on the mimetic spider which, without any anatomical significance in the internal arrangements, represents a real division in the ant. The eight-legged spider, without antennae, waves the front pair of legs in the air to resemble the mobile antennae of the six-legged ant, and it runs about with the movements of an ant. Mimicry, like the two other types of protective coloration, is very much an affair of the *living* insect.

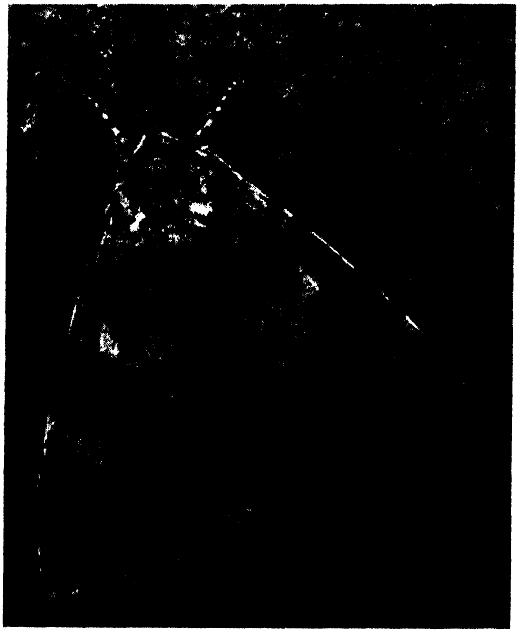
Mimicry has been intensively studied in butterflies, the tropical groups Danainae, Euploeinae, Ithomiinae and Acraeinae serving as models for species of the groups to which our 'Whites', 'Blues' and Nymphalines belong. Some butterflies mimic day-flying moths. Many beetles mimic ants, wasps or Ichneumon-flies, and two-winged flies do the same. Finally, Pseudaposematic coloration (Batesian mimicry) must not be thought of as a peculiar, isolated phenomenon. It is strictly comparable to special Pro-cryptic coloration. In both there is deceptive resemblance to an object not wanted for food: in the former case because it resembles another insect known to be objectionable, in the latter because it resembles an object of no food value. The literature on these subjects is enormous. The book by H. B. Cott *Adaptive Coloration in Animals* (London, 1940), contains very many references. For mimicry the reader will find an introduction in *Mimicry*, by Carpenter and Ford (London, 1933). A German book by F. S. Steiniger (*Warnen und Tarnen im Tierreich*, Giesen, 1938) contains some beautiful illustrations.



Butterflies of the genus *Flatta* hanging from a stem and looking very like flower-buds.

THE SENSES OF INSECTS

The only contact an animal can make with the world around is through its senses; and this statement applies with particular emphasis to the lower animals. Changes in temperature, humidity, light and other factors of the environment which call for accommodative or adaptive behaviour, can be appreciated only through some form of sense-perceptor. In insects generally the most obvious of these, after the eyes, and the most numerous, are those of touch, the hairs or setae scattered over the appendages, the legs and wings. Although the setae are non-living, each has at its base a sense-cell connected with the main nervous system by a nerve-fibre. We are most familiar with these tactile organs in the 'hairy' bodies of moths and butterflies, and the latter at least have a sufficiently well-developed sense of touch that they can distinguish readily between contact with a natural object, a leaf or a flower, and the touch of the human finger. The one causes no obvious reaction, the finger stimulates the insect to seek escape.



The Red Underwing Moth at rest on bark during the day.

The question must always arise whether the proximity of a human finger is detected by sight, smell or touch, and probably all three contribute. Under certain circumstances taste might be an operative, or contributory, sense, for in addition to the sense of taste lodged in the tongue, some butterflies have an auxiliary taste-organ on the tarsus of the hind-leg.

The sense of smell is located in the antennae, and the more elaborate these are, as in the feather-like antennae of the moth, the more we may be sure that smell enters into the equipment for living. For example, a male moth will find a female a mile or more distant. In addition, a sense of balance and of direction have also been shown by experiment to be located in the antennae.

Many insects possess elaborate organs of hearing. These are best known in insects producing obvious sounds, such as crickets and their relatives. In all cases, such organs consist of a tympanum, comparable with our ear-drum, connected with a nerve. Often they are of considerable size, especially in moths. They are absent in butterflies yet these insects can appreciate vibrations, and experiment has shown that the sense-receptors responsible are certain groups of setae in the front half of the body.

In addition to the sense-organs discussed above, there is good reason to suppose that others are present whose functions are as yet unknown. In other words, insect—and probably other animals—may possess senses which we have not yet even guessed at.

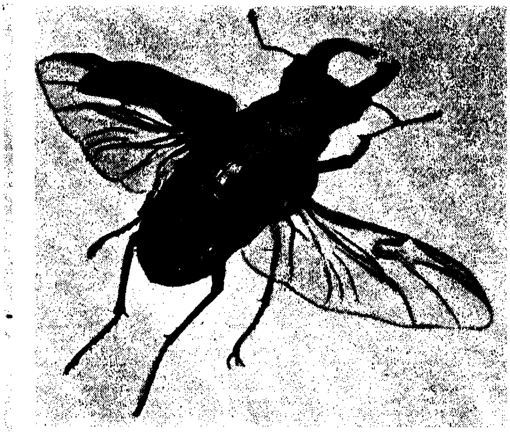
CHAPTER XX

THE INSECTS IV

THE SUB-CLASS ENDOPTERYGOTA

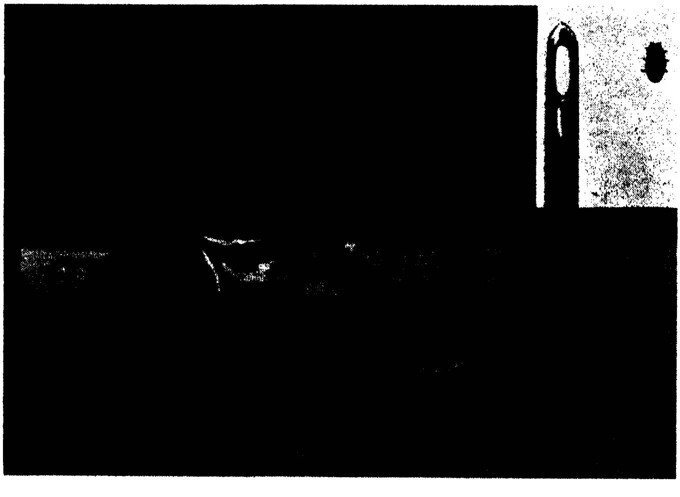
The Beetles; with an account of respiration in aquatic insects

ACCORDING to one authority more than 200,000 species of Coleoptera are already known and "it is almost certain that a million species exist in the world, many of them probably destined, as agriculture advances and primeval forests disappear, to vanish before they become known to science".



How to tell a Beetle.
Beetles differ from all other insects in having the front pair of wings hard and horny. They act as covers to the second pair which are membraneous. These horny front wings are knows as elytra. When flying the elytra are raised and the membraneous wings unfolded as in this picture of the Stag Beetle.

The most distinctive feature in the adult beetle are the fore-wings which have become thickened to form covers to the hind-wings, the latter being the only pair used in flying. When at rest these wing covers, or elytra, fit closely over the body, their inner edges meeting in a line down the middle of the back, and underneath them the membranous hind-wings are folded, usually both longitudinally and transversely. Some beetles have lost the power of flight, and the membranous wings are almost completely gone, and although the elytra are completely joined, the line of junction still shows.



The smallest and largest beetles. On the right a Pigmy Beetle (one of the Trichopterygidae) which can easily pass through the eye of a needle. On the left, the Goliath Beetle from W. Africa. Beetles are of considerable importance in man's affairs. Many weevils destroy crops, both standing and stored, and others, like Furniture Beetle, burrow in timber. On the other hand, others act as scavengers, like the Burying Beetles and Dung Beetles.

The order falls into two natural groups, or suborders, the Adephaga, including the predatory beetles, and the Polyphaga, including the rest.

Sub-order Adephaga
(Tiger-, Ground- and Water-beetles)

The *Tiger Beetles* are active, carnivorous beetles, usually inhabiting dry, sandy places. They

A beautiful Ground Beetle *(Carabus violaceus)*. The body is black with a purple sheen. The Ground Beetles, though less courageous than the Tiger Beetle, feed on all kinds of other insects and are not afraid to attack those larger than themselves. (Four times natural size.)

run quickly and take readily to the wing. Their colours, metallic green, bronze or black, banded or spotted with yellow, make them attractive to the collector. The larvae, rapacious and fierce as the adults, live in vertical burrows in the sand, with head hardly exposed at the entrance. On the approach of a victim they lunge forth from the burrow, seizing their prey in powerful jaws. On the back they have a pair of hooks which can be anchored in the walls of the burrow to prevent them being pulled out.

Not all Tiger Beetles can fly. The large *Mantichora*, of the African veldt, about two inches long, hunt their prey on foot. And the wingless Malayan species, *Tricondyla aptera*, pursues its victims among the foliage of trees and shrubs.

Ground Beetles. These form a large, world-wide family, black or dark brown in colour, although the European *Carabus violaceus* has a purple sheen, with a body about an inch long, flat and broad. It hides under stones and logs during the day, and is most active at night, mainly on the ground, although it can fly if necessary. Both the larva and the adult may be classed as beneficial since they feed on other insects, including the destructive Cockchafer, and the caterpillars of the Processionary and Gipsy Moths. Some species feed on snails also, and those belonging to the genus *Damaster* of Japan and China have the front part of the body elongated so that they are able to penetrate deeply into the snail's shell.

The Bombardier Beetles *(Brachinus)* discharge an offensive fluid from their anal glands which rapidly vaporises and at the same time explodes "with the noise of a pop-gun". This is defensive as both the sudden noise as well as the unpleasant nature of the discharge have a deterrent effect on a pursuer. *Brachinus displosor* can produce ten to twelve explosions in rapid succession. The fluid discharged by the Bombardier Beetles *(Anthia)* of Africa and India can cause pain if it comes in contact with the human skin. Related species living in the nests of ants and termites have much stouter antennae, which are luminous, and, by contrast, probably secrete a sweet fluid on which the ants and termites feed.

The *Carnivorous Water Beetles* are remarkably uniform in appearance, although there are over two thousand in fresh waters throughout the world. The body is somewhat flattened, oval in outline, black or dark in colour, and shiny, as though polished. The first pair of legs are used for seizing prey, the other two pairs are fringed with hairs and used in swimming. These beetles normally rest head down at the surface of the

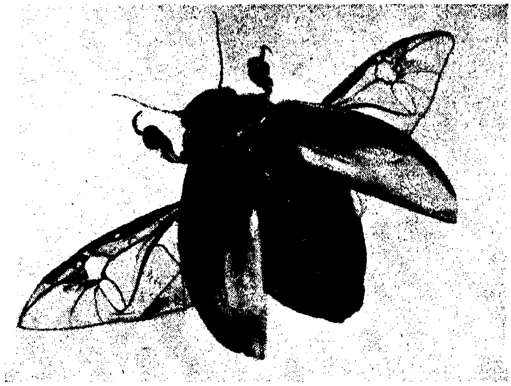
A Bombardier Beetle *(Brachinus crepitans)* of Europe pursued by a carnivorous Ground Beetle. A North American species which behaves in the same way is called *Brachinus fumans*. Both names are expressive of the tactics used. When the Bombardier Beetle is attacked by a carnivorous Ground Beetle it discharges an offensive fluid from the body which is converted into a puff of vapour with an explosion.

Perils of underwater life. A frog is being attacked and killed by a large carnivorous diving beetle.

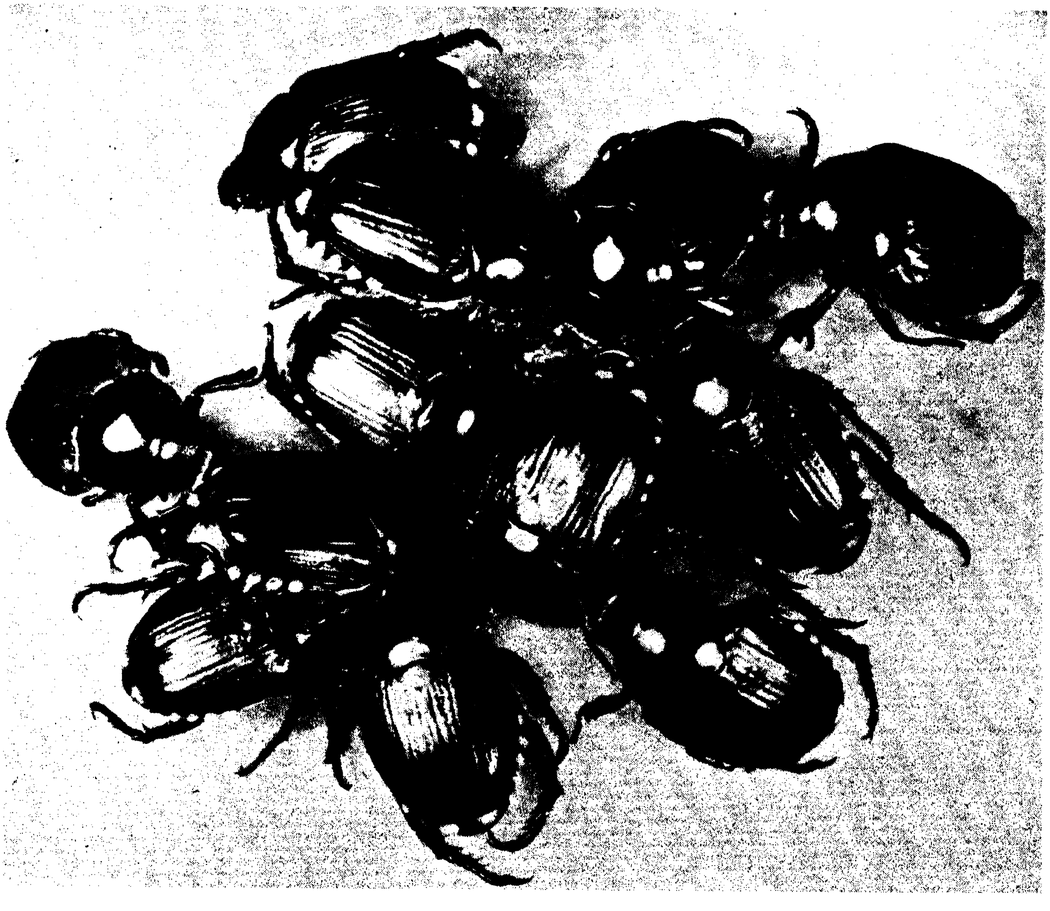
water with the tip of the abdomen protruding slightly through the surface film. They are able to take air in under the wing-covers, where it is available to the spiracles, and carry it with them when diving.

The larvae are as rapacious as the adults, and will eat each other if nothing else is readily available. The normal diet of both larva and the adult is, however, any small aquatic animal, even newts and small fish.

Whirligig Beetles are a familiar sight on the surface of still water, where they assemble in communities and spend their time darting swiftly around and about each other, tracing graceful curves on the water as they go. They are small, about a quarter of an inch long, with an oval shiny body, usually black or dark in colour. The antennae



The Great Carnivorous Water Beetle pushes the tip of its abdomen out of the water and takes air in under its wing cases. In this way it is able to breathe while diving and swimming. Here the beetle is seen in flight. (Natural size.)



A group of destructive Japanese Beetles eating into a peach. (Five times natural size.)

are inconspicuous, the front legs long and the other two pairs short, broad and paddle-like. They will dive readily if disturbed or pursued, and will fly on occasion from one pond to another. They feed on small flies and other insects that fall into the water.

The eyes consist of a pair on either side of the head, the upper one of each pair being used for vision above the water and the other, towards the undersurface of the head, for seeing under water.

The larva is conspicuous and lives in the mud at the bottom of the pond.

Sub-order Polyphaga

The first family is world-wide, its members living in damp earth, rotting wood or moist vegetable matter, preying on other insects. They may be recognised by their long narrow bodies, with small elytra, under which the membranous wings are folded, leaving the segments of the abdomen exposed to view. A typical example is the Devil's Coach Horse *(Ocypus olens)*. Others live in the nests of ants and termites, again supplying a sweet fluid on which their hosts feed.

Perhaps the most extraordinary extension of this habit is found in a small beetle, *Claviger testaceus*, only a tenth of an inch long, which lives always in the nests of the Yellow Ant. It gives off a sweet fluid which the ants eat, and in return they show every attention to the beetle's welfare. When hungry the beetle touches a passing ant and is then fed, the ant applying its mouth to that of the beetle and regurgitating into it a drop of nourishment.

By contrast, and as an example of the versatility of beetles, may be mentioned the Carpet Beetle, also known as the Carpet Bug or Buffalo Moth, of North America. The adult is black with irregular white markings and a red line down the centre of the back, about $\frac{3}{16}$ of an inch long. In this stage it is not a pest, but the larva, about a quarter of an inch long, with a coat of shaggy brown hairs, hence Buffalo Moth, feeds on furs, woollen fabrics and, particularly, on carpets that are left undisturbed.

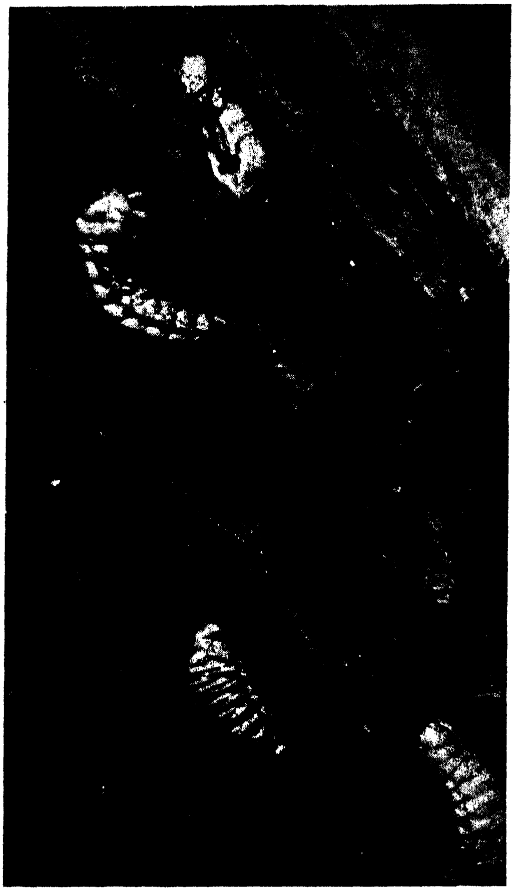
The *Burying Beetles*, or Sexton Beetles, black with orange markings, and found mainly in temperate regions, are scavengers of the first order. They are attracted to the carcases of small birds and mice, guided by smell, and work in groups pushing their way under the carcase and, with their stout legs, digging out the earth so that the carcase slowly sinks into the ground. Finally, the excavated soil, which is piled around it, falls in on the carcase completely burying it. The females then lay their eggs in the flesh

Burying Beetles are one of the natural scavengers. Here we see several of them about to start work on burying a dead bird. This is one reason why we so seldom see small dead animals lying about.

of the dead animal so that the grubs on hatching out will find a store of food near at hand.

The *Ladybird Beetles*, found in tropical and temperate regions, feed mainly on other insects or on their eggs, although a few are herbivorous. The larva is equally a pest-destroyer. The Two-spotted Ladybird *(Adalia bipunctata)* and the Seven-spotted Ladybird *(Coccinella septempunctata)* of Europe are well-known enemies of the plantlice or greenfly. The Australian Ladybird *(Vedalia cardinalis)* (see Chapter 18) is imported into California to deal with the Scale Insect pest on orange trees. The eggs of the Two-spotted Ladybird are yellow, and are laid in clusters on leaves. The small black larvae feed voraciously on all manner of small insects, and especially on the plant-lice. On the other hand, the Bean Ladybird, appropriately named *Epilachna cor-*

The Cosmopolitan Rice Weevil *(Calandra oryzae)* which is found wherever there are cargoes of grain. It is a destructive beetle and evidence of its work can be seen in the grains of wheat at the bottom of the picture.



Three larvae and a pupa (at the top) of the Death Watch Beetle *(Xestobium tessellatum)*. Some idea of the destructive work of the Death Watch Beetle is seen in this wooden beam where they have excavated their tunnels.

rupta, feeds on the leaves of bean-plants. Originally found in the south-western U.S.A., it has spread to the whole of the Eastern States.

The *Great Water Beetles*, of the family Hydrophilidae, have a strong resemblance to the Carnivorous Water Beetles, family Dytiscidae, already discussed, but are less predaceous, feeding mainly on water-snails. They breathe by trapping a bubble of air on the undersurface of the body. Air is taken into the tracheae through spiracles at the tip of the abdomen.

A well-known group of families includes the Woodworms, Furniture Beetles and Powder-post Beetles, all having a destructive effect on wood. The small round holes seen in furniture and the woodwork of old houses are the exit holes of the Furniture Beetle (*Anobium punctatum*). For nearly a year the larva spends its time burrowing in the wood, and the exit holes are merely the places where the fully-grown insects have eaten their way out. The Death Watch Beetle (*Xestobium tessellatum*) behaves in a similar manner except that the larval life lasts for two to three years. The superstition surrounding this beetle has arisen from its habit of tapping its head against the floor of its burrow, producing a mysterious ticking sound from the centre of the wood.

Fireflies are small beetles about half an inch long, which have a light-producing organ on the underside of the abdomen. The light flashes in a rhythmic pulsation, but what is more remarkable, many thousands of these beetles may often be seen flashing in unison. The *Glow-worm* is, again, a beetle, about an inch long, the female of which is wingless and grub-like. It, too, is luminous but the light emitted is more continuous than is that of the Fireflies. The male Glow-worm is able to fly and is less markedly luminous. Among the closely-related Soldier Beetles is a North American species in which, again, the females are grub-like. In the dark they show a line of green and red lights along the side of the body, and are known as Railway-worms.

The *Skipjacks* or *Click Beetles* feign death by lying on their backs if disturbed, and, having done so, spring into the air, when they want to right themselves, until they find a foothold. Some of the larvae are carnivorous, others are vegetarian, and among the latter is the destructive wireworm, a pest on potatoes and root crops. Click beetles range from a tenth of an inch long. Certain species of tropical South America have a pair of luminous areas on the back, and are known as Automobile Bugs.

The largest of the Click Beetles, *Tetralobus flabellicornis*, lives in the larval stage in the termite nests in Africa and is often mistaken for the queen termite.

The *Oil Beetles* and *Blister Beetles* are grey to black, up to about an inch long, and their larvae have remarkable parasitic habits. The adults have the power of producing a highly irritant fluid capable of raising a blister on the human skin. From their dead bodies the extract cantharadin is obtained. The eggs are small and yellow and large numbers are laid just under the surface of the soil. The larvae on hatching swarm on to the neighbouring plants and settle on the flowers. When one of the solitary bees visits a flower a larva will take a grip on one of the bee's hairs, to be carried away to its nest. If the bee is a female the larva holds on until she has filled the cell with honey and laid her egg in it. Then it drops off and devours the egg. At this stage it cannot eat honey, but later it moults, undergoes a change in shape, and acquires mouth-parts enabling it to suck the honey.

The Lamellicorn Beetles include some of the largest as well as some of the most extraordinary of all the Coleoptera. The Stag Beetle *(Lucanus cervus)* has enormously elongated jaws resembling stag's horns. The Hercules Beetle *(Dynastes hercules)* has long outgrowths of the head and thorax and the Rhinoceros Beetle *(Oryctes boas)* bears a single 'horn' on its head like the mammal after which it is named. Included in the group also are the Scarab or Dung Beetles, sometimes called Tumble Beetles, including the Sacred Beetle of Egypt. Most of them, in spite of their size and formidable appearance, feed on decaying vegetation, carrion, dung or rotting wood, but the Rhinoceros Beetle, which burrows into the wood of coconut palms, does a good deal of damage.

The Scarabs have the curious habit of collecting balls of dung and rolling them along. The ball, which is pushed backwards with the hind pair of legs, was formerly believed to contain an egg, but this has been proved to be incorrect, although a similar ball is prepared for the egg in a previously excavated chamber in the ground. When rolling a ball for its own food supply, the Scarab is liable to attack from other members of its own species, who endeavour to drive it off and take possession of the prize.

The large Mexican Scarab Beetle rolling its ball of dung to a suitable place where it can bury it and feed on it.

One of the carrion-feeding beetles related to the Burying Beetles. This one, *Silpha sinuosa*, is less than half an inch long and dull brown in colour. Here it is seen laying its eggs in the carcase of a Dung Beetle. The ovipositor can be seen extended backwards from the tip of the beetle's abdomen.

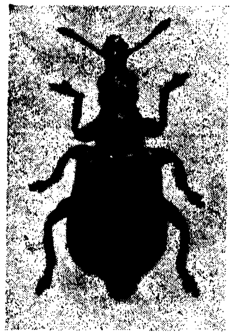
In a related group of species of the genus *Gymnopleurus*, the ball is rolled by a male and a female, the latter being always behind the ball and pushing it, the male being in front. Should either of the pair be attacked and driven off, the newcomer is readily accepted by the second partner and the ball-rolling is continued. Having reached a suitable spot, they excavate the earth under the ball until it sinks completely into it. They then proceed to eat until only the outer crust is left.

The members of *Gymnopleurus* are unpalatable to beetle-eating predators, such as birds, and it is of interest to note that they are often mimicked by other insects.

In another group of Lamellicorn beetles, the Cockchafers, we have an interesting example of a multiplicity of common names. The Cockchafer or May Bug (*Melolontha vulgaris*) of Europe has its counterpart in the U.S.A., where several species of the genus *Lachnosterna* are known, in the northern states, as June Beetles or June Bugs, in the southern states, as May Beetles or May Bugs. Another name for them, or at least for their larvae, is White Grubs.

The larvae of these beetles feed on roots and the adults on leaves. The former are white and plump, with a brown head, and spend up to three years in the soil. The adults are brownish, a little more than an inch long, and live only a few weeks, but during that time are apt to be plentiful, and particularly noticeable because of their habit of flying into houses of an evening attracted by the light.

The *Longicorn Beetles* have unusually long antennae, hence the name, and are mainly woodborers. They are remarkable for the way both elytra and wings are coloured. There is in this group a strong tendency to use colouring for protection. Those that are active by day resemble wasps or hornets, with which they often associate, and those that are active by night and rest by day tend to resemble the lichens on which they rest.



A magnified picture of *Rhynchites betulae*, the Birch Leaf-rolling Weevil.

The next group, which includes the *Colorado Beetle*, is noted for the brilliant colours possessed by many of its members, which are often linked with poisonous or otherwise unpalatable properties. Such brilliant colours act as a warning to would-be predators (see Chapter 17).

One species living in the Kalahari Desert is used by the natives for poisoning arrow-heads, and the poison squeezed from their bodies and used this way has a deadly effect on lions and other large animals.

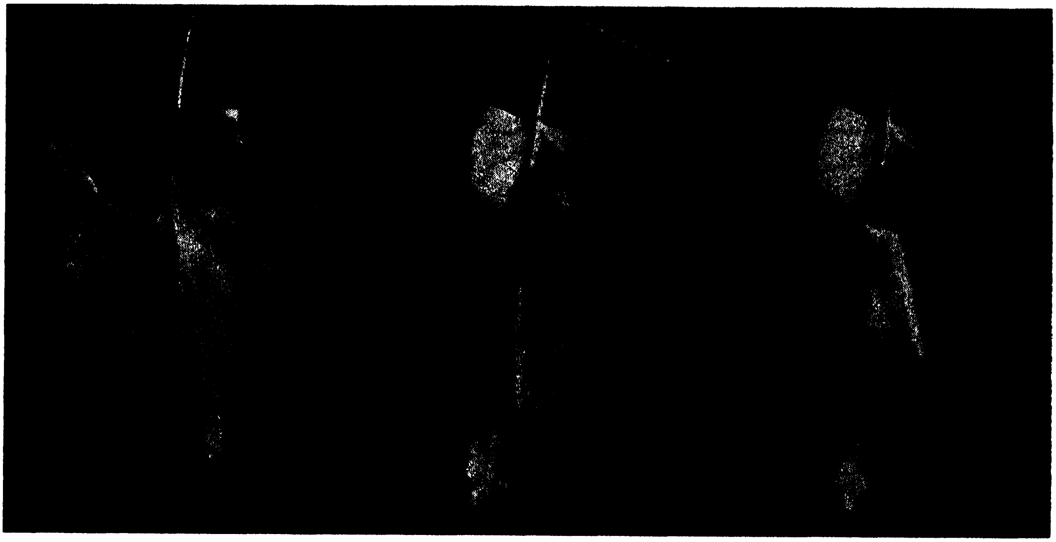
The Colorado Beetle is an example of what happens when man interferes with natural things. Prior to 1850, this beetle lived a blameless existence on the eastern slopes of the Rockies, feeding on weeds belonging to the Potato family. Then settlers introduced the potato plant itself and the beetle took readily to it as a source of food. In the following years it spread from one patch of potatoes to another until by 1874 it had reached the Atlantic seaboard. Then it started to spread north into Canada. In 1922 it became established in Europe and now constitutes a pest, particularly in France, that needs constant watching. The adults, which are broadly oval and ⅜ of an inch long, have the elytra marked by black and yellow longitudinal stripes, five of each.

The adults spend the winter at a depth of ten inches in the soil, coming out in the spring to feed on the young potato shoots. The female lays her eggs, about 500 in all, on the potato leaves, and from these emerge the reddish hump-backed larvae, marked with a double rows of black spots down each side. After feeding on the potato leaves, they retire to the earth to pupate, and about ten days later the adult insect emerges, to start a second cycle in the season.

The last group of the Coleoptera, the *Weevils*, includes a large number of species of very destructive insects. Although of small size their ravages, of growing crops and stored grain, are the cause of considerable loss. Weevils can be readily recognised by the snout, often quite long and slender, at the end of which the mouth is placed. The larvae are legless grubs living in the tissues of plants. The Palm Weevils attack the trees from ground level, eating their way up and hollowing the trunk out as they go. The Rice Weevil is found wherever this form of grain is carried or stored. The Cotton-Boll Weevil is another very destructive pest.

Another group of weevils is remarkable for its habit of leaf-rolling. The female cuts through a part of the leaf so that it hangs down. In this she lays an egg and rolls the leaf round it to provide shelter and protection.

The *Shot-hole Borers* or *Bark Beetles* are very small beetles that make the minute holes often seen in trunks and branches of unhealthy trees. The female bores through the bark, then tunnels between it and the wood, laying her eggs at regular intervals on each side. The grubs that hatch out proceed to tunnel at right angles to



The weevil, on the left, has made its preliminary cuts in the leaf. In the centre picture, it was gone to the underside of the leaf and has commenced rolling operations. On the right, the rolling is half done.

the brood tunnel, so forming a balanced pattern which is exposed when the bark is peeled off. Having matured, each grub pupates at the end of its burrow and the adult insect escapes by boring. The *Ambrosia Beetles*, another of the Weevil group, feed on the mildews growing on the walls of the tunnels they make in wood. They are said to prepare a special compost on which they plant the fungus spores specially gathered. The larvae are fed on the fungus.

Finally, we come to a group of Weevils, the Brenthidae, in which the elongation of the snout has not only been taken to an extreme length, but the rest of the body and the legs are also elongated so that the beetles come to resemble Stick Insects.

The weevil, on the left, is working inside the leaf—out of sight. In the centre, the rolling is almost complete—the weevil still inside. At this stage the weevil lays an egg within the folds of the leaf. The beetle is, on the right, fixing the rolled-up leaf. Here the tip of the leaf had been neatly tucked in, and the weevil has returned to the unrolled portion. Before going elsewhere, she partially cuts through the midrib above her roll.

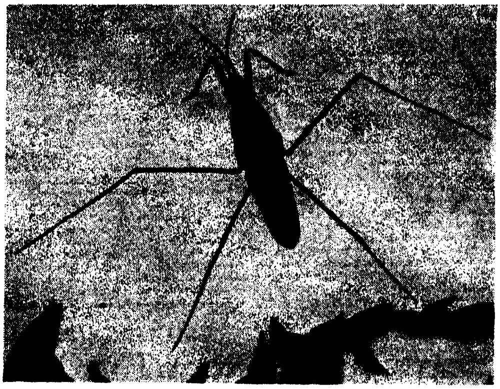
RESPIRATION IN AQUATIC INSECTS

by

DR. G. BARENDRECHT

(Most of the special articles contributed deal with their subject in a general way. This article, dealing with only one aspect of the life of aquatic insects, exemplifies the kind of detailed research now being pursued in all fields of zoology)

Their anatomy, physiology and biology can be understood only if we regard insects as animals particularly well adapted to a terrestrial life, for, contrary to the usually accepted idea, it is not an aquatic life which presents difficulty but life on land, the chief problem to be solved being that of respiration. These insects have solved in a remarkable way. It is the combination of a rigid cuticle, impermeable to water, with a tracheal system communicating with the atmosphere through a series of spiracles, that has made them so successful. The cuticle, in addition to being an ideal skeleton for small animals, is an almost perfect safeguard against desiccation and has been the main cause of their astonishing development. In fact, a more complete conquest of land and air can hardly be imagined.



Gerris thoracia, a Pond Skater. .

It is, therefore, the more remarkable, that throughout the evolution of this class there have been forms that have returned to an aquatic life. This process started among the more primitive members, such as may-flies, dragon-flies, and stone-flies, and proceeded through the orders of bugs, lace-wings and caddis-flies up to the beetles, wasps and flies. Even among the moths we meet with aquatic species. Almost every order has produced aquatic insects, some of them, like the Odonata (dragon-flies) and the Ephemeroptera (may-flies), having only aquatic species. Now there exists a considerable diversity in the way as well as in the degree to which these insects have become aquatic. To begin with, we find those that live not *in* the water but *on the surface* of the water. Such insects bear about the same relationship to real aquatic insects as water birds like the geese do to the fishes. In them it is not so much the respiratory system that shows special adaptations as the locomotory apparatus. The most generally known example is furnished by the Gerridae, the pond-skaters of our ditches, long and slender predatory bugs, which walk upon the surface of the water as other insects do on the earth. The surface tension is great enough to bear the weight of these small animals, the more so as it is divided over six rather widely separated points. In the same way many Collembola or spring-tails live on the water, feeding on algae and other microscopical organisms. In their turn they form the principal food supply of the skaters and the Gyrinidae or whirligig-beetles. All these are air-breathers unable to survive more than a very short immersion.

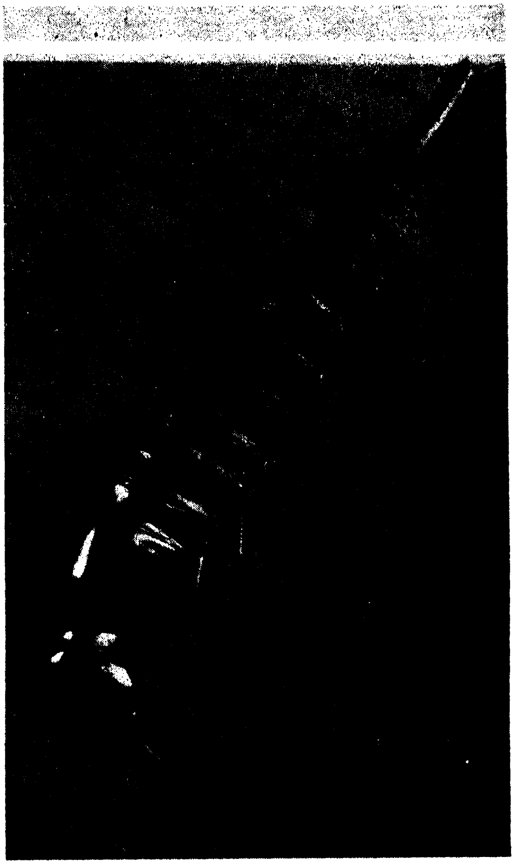
A transition from these surface-dwellers to the genuine or submerged aquatic insects is seen in the whirligig-beetles, which spend most of their active life on the border of air and water, hunting Collembola and other small animals, but are able to dive and remain for a considerable time below the surface.

Their swimming legs and streamlined body are beautifully adapted for swimming, and the eyes, divided in a peculiar way, enable them to perceive things on the surface with the upper half, while the lower portions surveys the world under the surface. Their highly specialized antennae keep them constantly aware of changes in inclination of the water level, and it is probable that in this way, by perceiving a hollow meniscus, they are able to avoid collision with such solid objects as stalks of plants, the bank, enemies, etc. The larvae of these beetles are aquatic too and live permanently submerged.

The example of the whirligig-beetles serves to emphasize that one-half of the genuine aquatic insects pass all their life in the water, while in the other half only the larval life is aquatic, the insects becoming terrestrial after completing their metamorphosis. It is most striking that, so far as respiration is concerned, the former are less completely adapted to aquatic life than the latter!

Before considering the different ways in which aquatic insects are adapted to respiration under water, we should bear in mind the very different way in which oxygen is at the organism's disposal in the atmosphere and in the water. Since air contains about 20.9 % of oxygen, we may put the partial pressure of oxygen at approximately 1/5 atm. The diffusion constant in air is so high that a measurable reduction of the pressure of oxygen at the animal's surface is unimaginable. It is only within the respiratory tract that the concentration of oxygen sinks below that of the atmosphere, thus making respiratory, that is ventilatory, movements indispensable. In water it is quite different. To be sure, the partial pressure, at least in the upper layers where most of the insects are living, is quite as great as in the air, since there must be a balance between the two pressures. But, the diffusion constant in water being much lower than in air, aquatic animals will have at a certain point in a certain space of time much less oxygen at their disposal than terrestrial animals. Therefore, in aquatic animals various means are employed to ensure that a large amount of water will be carried along the respiratory surfaces in a short space of time. The best-known example is the gills of fishes, along which a continuous current of water flows. In several types of insects we shall meet with an analogous arrangement.

The large group of water-beetles and bugs solve the problem in what appears to be a somewhat roundabout way. Although living and feeding in water, they rise periodically to the surface to obtain a fresh store of air, an apparently clumsy method compared with that employed by the larvae of mosquitoes, several species of hover-flies (Syrphidae) and flies of the family Stratiomyidae, all of which are in permanent communication with the atmosphere by means of a longer or shorter respiratory tube. In the Eristalinae (a group of hover-flies) this tube, inserted at the end of the abdomen, may be extended many times the length of the body, thus enabling them to live in putrefying mud, rich in food but almost devoid of oxygen, at the bottoms of shallow ditches. On the other hand, mosquito larvae with their short respiratory tube are

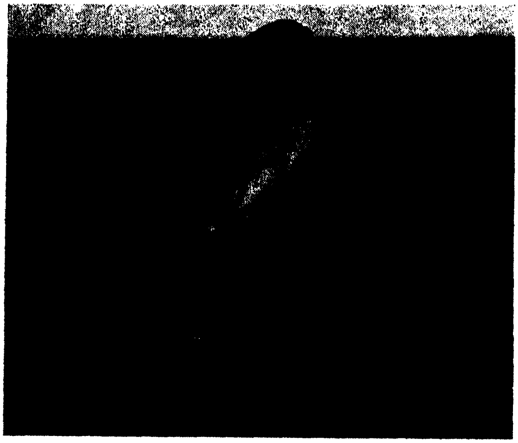


The larva of *Dytiscus*, the Great Water Beetle, taking breath at the surface through the tip of the abdomen.

suspended from the surface film and the pupae of these insects respire in the same way by means of two prothoracic horns.

If, by chance, any of these insects have to remain submerged for a time, they draw upon the store of oxygen in their tracheal system.

Returning to the water beetles and bugs we find that appearances are deceptive: their apparently clumsy method of breathing is ingenious in the extreme. When, after a short time at the surface, these insects dive, they carry with them a stock of air. Thus, *Hydrous piceus* carries the air under the elytra and in a thin film between the hairs on the underside of the body, which is rendered quite silvery by it; *Dytiscus marginalis* has its air reservoir under the elytra; *Notonecta glauca* has two double rows of long hairs on the underside of the abdomen. But in all these instances the stock of air is more than a mere store to be consumed during the insect's stay under water: it is also to enable the animal to take the oxygen dissolved in the water. These insects are only apparently dependent on the oxygen in the air; in fact, they obtain their main supply from the gas dissolved in the water. But in what way is this managed? The bubble of air, as it is originally carried off, contains about 22.9% of oxygen, 75.3% of nitrogen, and 0.03% of carbon dioxide. The insect takes some oxygen from the bubble, thus lowering the partial pressure of the rest. As we have seen, in water the partial pressure is the same as in the air, viz. 1/5 atm. So, oxygen will diffuse from the water into the bubble until the balance is restored. This arrangement enables the insect to remain much longer below the surface than would be expected from the size of the original bubble. Yet this cannot go on indefinitely, for the air bubble gradually grows smaller and at last would be quite gone. For oxygen is constantly consumed, so that in reality there never will be a complete balance with the oxygen in the water. On the other hand, the carbon dioxide produced diffuses some 30 times more quickly than the oxygen consumed, so that the partial pressure of this gas will stay at about the same level. But, as the total pressure of all the gases will be constant, namely 1 atm., the height of the water column, the partial pressure of nitrogen will rise so as to cause diffusion of this gas into the water, thereby diminishing the size of the air mass. Eventually, the bubble would vanish completely, but before reaching this critical point, the insect will rise to the surface to lay in a new store of air. Peculiarly enough, this method is not effective if, under laboratory conditions, the insects are compelled to lay in a store of pure oxygen instead of air. Then the gas bubble will decrease rapidly in size and asphyxiation comes much sooner than under normal conditions. On the other hand, it is very well possible for another neutral gas to take the place of nitrogen—for example, marsh gas—as will happen often in winter when the water is frozen.



Dytiscus, the Great Water Beetle, taking in air at the surface.

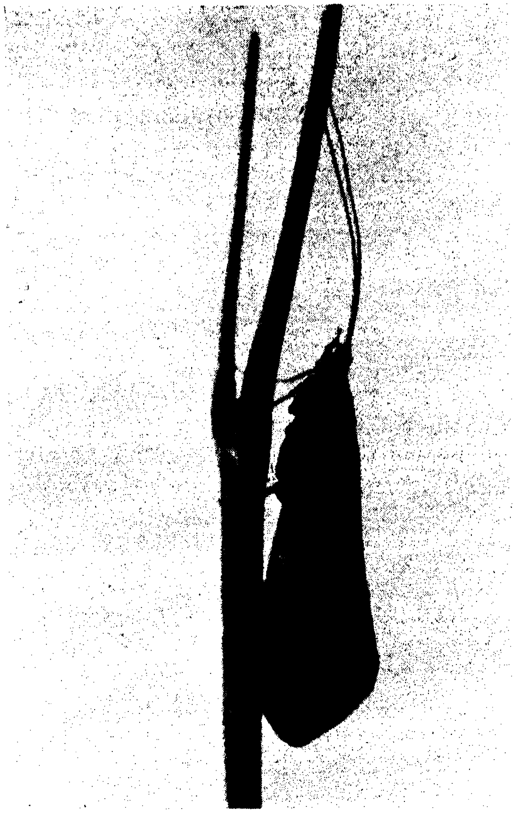
So these beetles and bugs are better adapted to aquatic life than the tube-respiring larvae mentioned before. The process of adaptation has, however, proceeded still further, for a number of aquatic larvae no longer need the oxygen of the air, as they are equipped with gills enabling them to take the oxygen dissolved in the water.

Essentially, these gills are of two kinds, viz. tracheal gills and blood gills. In those with blood gills the tracheal system is non-functional. The tracheae, if present, are filled with liquid and the principal respiratory organ is the integument, whose surface is often enlarged by slender appendages, the blood gills. The best-known examples are the caddis-worms and the larvae of Tendipedidae (non-biting midges, harlequin-flies), both of which generally have blood gills at the end of the abdomen. In caddis-worms these originate from the rectum. But even when organs that apparently are blood gills are present, most of the respiration will take place through the general integument. This is also the case in the early stages of insects which later breathe by tracheal gills.

Many species of Tendipedidae are unique among insects in having haemoglobin in their blood. As this is, however, dissolved in the blood plasma and red blood cells are wanting, the total amount is very small. It is supposed to enable the blood to persist in its function as a carrier of oxygen even if the pressure of oxygen grows very low. For in all these larvae without air-filled tracheae, oxygen must be transported by the blood, a very anomalous arrangement in the insect world!

Tracheal gills combine the advantages of gill-respiration and of the tracheal system. Consequently, they are of common occurrence in the various orders of insects. The larvae of dragon-flies, may-flies, stone-flies, several groups of Neuroptera and water-beetles, the caddis-worms, all bear tracheal gills of the most varied shape and origin. Mostly, they take the form of segmentally inserted filaments or lamellae. In the larvae of *Sialis* (a Neuropteron) and *Gyrinus* (the whirligig-beetle) the abdominal legs function as tracheal gills; in the dragon-fly larvae of the sub-order Anisoptera they form a complicated set of folds in the wall of the rectum. Common to all tracheal gills is the presence of many tracheae and tracheoles in close contact with the integument, thus allowing a free passage of oxygen. Between the gas mixture in the tracheal system and the gases dissolved in the water there exists a similar exchange as we have found in the insects carrying a store of air on the outside of their body. With one important difference, however:

A Caddis-worm in its house made of twigs. Any handy material serves to decorate the tube in which the worm lives, sand-grains, small shells and the like. At the tip of the abdomen the larva has a pair of hooks by which it can anchor itself in the tube. In this way it can crawl about seeking food, dragging its house with it and retiring therein at the first sign of danger. (Twice natural size.)



An adult caddis-fly *(Phyganea)* at rest on a stem. (Three times natural size.)

nitrogen does not gradually disappear from the tracheae and the insects are, therefore, able to stay permanently submerged. For recent investigations have demonstrated that the pressure within the tracheal system is 1/10 atm. lower than in the water. Therefore, no nitrogen will diffuse into the water. The difference in pressure is borne by the wall of the tracheae. Now the actual pressure of the gases in the water never will be more than 1 atm., this being the pressure at the surface of the water, where they are in equilibrium with the atmospheric air and so the pressure within the tracheae must of necessity be less than 1 atm. On the other hand, every 10 m. of water increases the pressure to be borne by the tracheae by another atmosphere and so the occurrence of tracheal gill-bearing insects is limited to shallow waters. To be effective, the tracheal gills need, of course, a constant fresh supply of water. In many larvae the general movements of the body will suffice, but in sessile larvae special "ventilatory" movements are indispensable. The caddis-worms, for example, maintain a continuous current of water through their cases by undulating movements that are even continued by the pupa. The larvae of the Anisoptera alternately take water into the rectum and expel it. If this is done forcibly, the larva propels itself forward, thus exhibiting a principle generally considered very modern: jet propulsion!

Compared with respiration, every other problem offered by the transition from terrestrial to aquatic is of only secondary order. Feeding, for example, does not differ essentially from that on land, except in plankton feeders. These latter are among the Corixidae (water-bugs), Melusinidae (small biting gnats), inhabiting in their larval stages rapids and waterfalls, and some of the net-constructing caddis-worms.

CHAPTER XXI

INSECTS V

THE SUB-CLASS ENDOPTERYGOTA

The Hymenoptera: Ants, Wasps, Bees

THE Hymenoptera can be recognised by the following characters: the usual division of the body into head, thorax, and abdomen appears obvious, but in fact the first segment of the abdomen is joined with the thorax, and the next few segments are markedly narrow to form the waist, a conspicuous feature of most species of Hymenoptera. There are two pairs of wings, although these are often absent, as in ants. They are without the scales characteristic of the Lepidoptera, but are membranous, shiny and often brightly coloured. The head is freely movable. The females always have an ovipositor, which is often modified to form the sting. The stages in the life-history include the egg, the larva, usually an inactive grub, a resting pupa and the adult.

The best-known Hymenoptera, the bees and ants, have developed a social organisation far exceeding that of any living creature other than man. This is dealt with more fully at the end of this chapter. The class is divided into the Phytophaga, or vegetable-eaters, including Horn-tails and Sawflies, the Parasitica, parasitic and gall-forming insects, and the Aculeata, ants, bees and wasps.

Sub-order Phytophaga

The members of this sub-order do not show the waist characteristic of the other Hymenoptera. On the whole, too, they are less graceful, and certainly not so active and sensitive. The larvae of the Horn-tails bore into wood, those of the

A Hymenopterous insect, *Pelecinus*, with an unusually long abdomen. The female lays her eggs in the bodies of beetle larvae found in decaying wood.

Stem Saw-flies into the stems of plants, and those of the true Saw-flies feed on the leaves of trees and shrubs. The latter can be readily mistaken for the caterpillars of Lepidoptera, except for one feature of their behaviour: when disturbed they curl the last few segments of the abdomen under themselves, after which they quickly raise and lower this part of the body. Most of the larvae pupate in or near the surface of the ground, and make a slight cocoon, but those living in wood or woody stems pupate in the tunnels they have bored.

Parthenogenesis is very common among saw-flies. In many species only females are known. Whether the males exist is not known, certainly they have not been found yet.

Sub-order Parasitica
(Ichneumon-flies, gall-flies)

These are mostly of small size, and although nearly 50,000 species are known it is probable that there are many more as yet unknown. In appearance they are more like the ants, bees and wasps, the typical waist being usually well-marked, but the ovipositor is never converted into a sting.

The female Gall-flies lay their eggs in the tissues of plants. The grubs hatching from them cause an abnormal growth of the plant-cells with the resulting formation of galls of varying shapes and forms, according to the species of fly concerned. They are small inconspicuous insects, usually black or darkly-coloured, better known by the results of their actions than they are themselves. In many species the males have not been seen although a very close search for them has been made. In other species there may be males and females in one generation and females only in the next. For example, *Biorhiza pallida* has two distinct generations with quite different habits. It lays its eggs in the buds of the oak and causes them to form the well-known "oak-apples". The grubs hatching out give rise eventually to both male and female flies. These mate and the females lay their eggs in the roots of the oak, but the grubs hatching from this generation of eggs grow into females only, which lay their eggs in the buds and so the cycle is completed. There is, therefore, a root-gall generation from eggs fertilised in the normal way, and a bud-gall generation from eggs laid by parthenogenetic females, an alternation known as heterogeny.

Among the gall-flies we find then generation after generation without, apparently, any males, of males and females in one generation and females only in the next (heterogeny), or species in which the males can always be found but are much fewer in numbers than the females. Such a condition can readily lead to that found in bees and ants where the females play such an important part in the life of the colony, the males being subordinated to the function of mere fertilizers of eggs.

The rest of the Parasitica prey on animals and show a wide range of tactics to do this. The eggs may be laid either near the insects on which the grubs will feed, or on the skin of the host so that the grub on hatching out bores its way in; or they may be laid actually inside the host. Many species are egg-parasites, laying their eggs in those of other insects. In some case, as many as twenty eggs of the parasite will be laid in the egg of a butterfly. In certain other cases, there occurs a curious process known as poly-embryony. The embryo of the parasite's egg will itself divide again and again to give rise ultimately to up to a hundred grubs all living in one caterpillar. Some of these parasitic flies can actually swim under water in search of the eggs of water bugs.

The Lacewing-fly lays hers eggs in groups on leaves, and each egg is stalked. The young larvae are rapacious and, but for this device, the first to hatch would probably eat the rest. There is, however, a species, *Perilampus chrysopae*, belonging to the Parasitica, that lays its eggs on leaves. The grubs hatching from them are very active and crawl about in search of the Lacewing larva, to crawl on to its body and burrow through the skin. Sometimes the *Perilampus* grub will climb the stalk of a Lacewing egg and lie in wait for the larva to hatch out. There is another species, *Orasema viridis*, of Texas, a minute fly less than one-hundredth of an inch long, the females of which lay their eggs by the hundred in ant's nests. The grubs from these parasitise the ants. A second species of *Perilampus*, *P. hyalinus*, lives on the fly-maggots infesting certain caterpillars. The female *Perilampus* lays her eggs on the skin of the caterpillar. The grubs hatching out bore through the skin and wait in the caterpillar's body for the fly to lay its eggs. Then when the fly-maggot hatches out, the *Perilampus* larva bores its way into it.

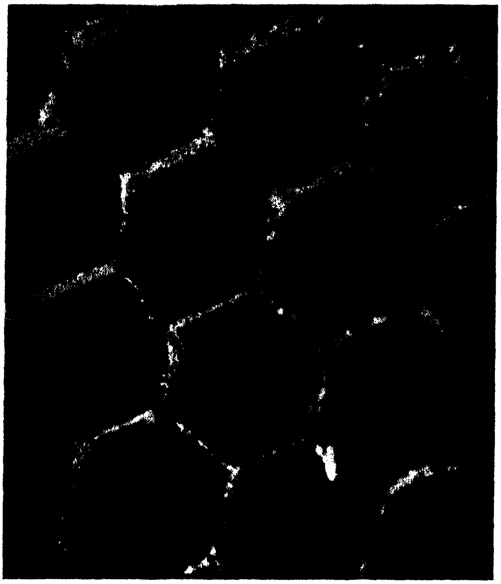
Head of an ant (*Camponotus* sp.) to show the long sensitive antennae and one of the compound eyes. One simple eye may be seen on its forehead.

The last of the Parasitica, the Ichenumon-flies, are beneficial in the sense that they parasitise insects that are pests to man. The various species of *Praon* and *Aphidius* lay their eggs in the bodies of aphides. The results of their work can be readily seen on any plant heavily infested with greenfly. The grub hatching from the egg of a *Praon* feeds on the contents of the body of the greenfly until it is fully grown, then it splits the skin of its host, forms a pedestal-like cocoon on which the dead body of the *Aphis* is perched. A similar thing happens where the parasite belongs to a species of *Aphidius*, except that the dead body of the host is merely cemented to the leaf and the grub pupates within it. During this process the body of the greenfly goes a straw colour and looks dry and somewhat bloated.

The female of *Rhyssa persuasoria* is able to drive her ovipositor through bark and lay her eggs beside those of the Giant Wood-wasp (*Sirex gigas*) the *Rhyssa* grub later parasitising the *Sirex* grub. The species of *Thalessa* have even longer ovipositors, often as much as six inches long, that is longer than the body itself, for penetrating deep into the wood to lay their eggs beside those of their victims.

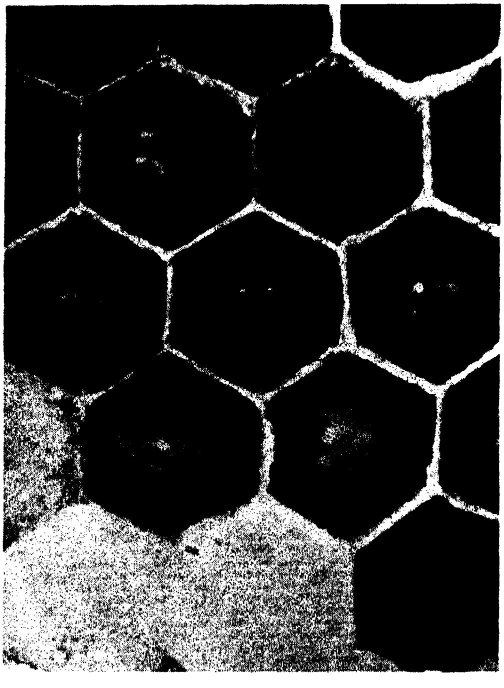
Polynema natans swims under water by means of its wings, seeking out the eggs of Water Boatmen (*Notonecta*) in order to parasitise them.

Perhaps the strangest of all is, however, *Riela*



Wasps' eggs are laid on the sides of the cells, where they adhere by reason of a sticky material at their ends.

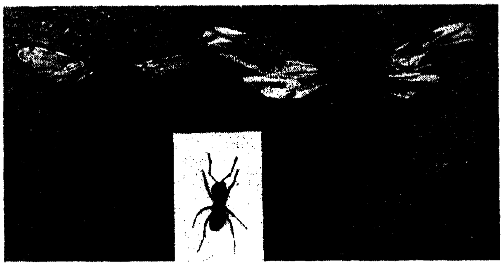
manticida, which passes it larval and pupal life in the eggs of the Praying Mantis. The adult emerges from the Mantis eggs and makes its way to a female Mantis. Once on the body, the *Riela* loses its wings and becomes an ectoparasite. If the Mantis is a female the female *Riela* makes its way to the tip of her abdomen at egg-laying time, and lays her eggs on those of the Mantis. Presumably if the *Riela* gets on to a male Mantis it eventually dies without having contributed to posterity.



Wasps' comb with full-fed grubs, several of which have already capped their cells.

Sub-order Aculeata
(Ants, Wasps and Bees)

Although some members of this sub-order are strikingly like some of the Parasitica, and indeed have often been included with them in a single grouping, the Aculeata are marked off by the fact that their larvae are practically helpless and are either provided with a readily-accessible store of food, or are actually fed by the adults. All activity is, therefore, confined to the adult insects and the larvae and pupae are hidden away.



The division of labour. The ant *(Lasius flavus)*, showing the winged male (left) and female (right) as seen at the time of swarming, and a wingless worker.

Ants. All the 6,000 species of ants from various parts of the world are social. In almost all cases there are three distinct castes: the males, the fertile females or queens, and the sterile females or workers. The males are winged, have small heads and long antennae, and have both sense-organs and reproductive organs highly developed. The queens are large compared with the males or the workers, are at first winged but shed their wings after pairing. Their jaws, legs and, of course, their reproductive organs are strongly developed. In the workers the head is large compared with the rest of the body, and the jaws, legs and antennae are well-developed. In all species the workers vary in size, and in some species there are two well-marked groups, one of which, having especially large heads and jaws are known as the soldiers.

Although ants live in colonies separated from each other by, often, considerable distances, there comes a time when this isolation breaks down, as indeed it must to preserve the vigour of the race by interbreeding. So, in due season, the winged queens over a wide area leave the nests to indulge in nuptial flight, during the course of which they are impregnated by the males. Once they are fertilised, the queens come to earth, bite off their wings, fashion a chamber in the earth and there lay their eggs. To begin with each queen has the task of feeding the larvae. This she does from her salivary glands, or even by feeding some of the unhatched eggs to the larvae. In time she raises a brood of sexually-undeveloped, or infertile, females to form the workers, or the workers and the soldiers, according to the species.

A queen wasp hibernating.

With the development of the brood the colony grows and the nest takes shape. It may be under the earth, or made of earth or of vegetable waste, such as pine needles, or in decaying wood. Once the colony is formed the workers take on the task of building the nest, keeping it clean, tending the eggs, feeding the larvae and even feeding the queen herself, or the queens, for there may be more than one in a colony.

All but the more primitive ants are vegetarian and consequently do not have to search far for food. Some species have gone further, however, and have developed agrarian habits, planting seeds

Young adult wasps break through the tough silken caps spun over the cell by the fully-fed grubs.

A queen wasp crawling on a piece of comb.

and harvesting the products. Others collect and store decaying vegetation and feed on the fungi which grow on it. Finally, yet others feed on the honey-dew from plant-lice.

From using other insects for their secretions, as is the case with plant-lice, some species of ant take other insects into their nests for this purpose. In addition, there is a very wide range of insects that may be found in the different nests. Some insects merely live in the nests, some act as scavengers, some even feed on the ant's eggs and larvae in addition to obtaining free lodging. Again, more than one species may voluntarily inhabit the same nest; or there are those, like the Red Robber Ants, which make slaves of other species. The Harvester Ants of America, grow their own "ant-rice" in clearings around the nests. The Parasol Ants of Tropical America gather leaves on which fungi grow.

Perhaps the most remarkable adaptation is found in the Honey-pot Ants of North America, South Africa and Australia. In these some of the workers do nothing more than act as receptacles for the honey and honey-dew collected by the rest of the workers. These "honey-pots" hang permanently from the roofs of the nests, their abdomens swollen enormously with honey.

Of the carnivorous species, the Pomerine ants of Australia are the most primitive group. Their colonies consist of about a dozen individuals and there is little difference between the castes. Some, the Bulldog Ants, are about one inch long, and unusually ferocious. The Driver and Legionary Ants are of nomadic habit, moving about, denuding the land of all insects as they pass.

The sharpness of a wasp's sting (right) compared with the point of a needle.

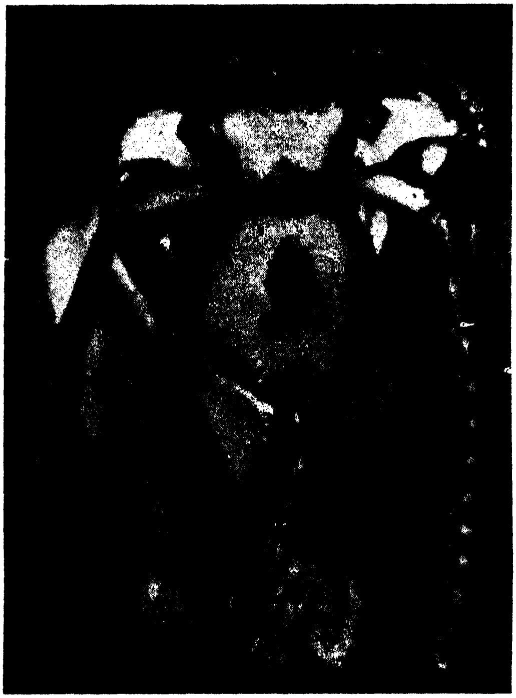
At the end of the season, when food is scarce, wasps tend to throw their larvae out of the nests in large numbers.

Wasps. There are two main groups of wasps, the Vespoid, or True Wasps, and the Sphecoid or Digger Wasps. Not only are the two groups distinguished by small differences in the structure of the body, but more obviously in their habits.

The Vespoid wasps include species that are solitary in habit, as well as those that form colonies. The Sphecoid wasps, on the other hand, are all solitary.

The most primitive wasps are those known as Flower-wasps and the Velvet-wasps, also called "solitary-ants". Both have this in common, that the females are wingless and very like ants in appearance, the males being winged and much larger than the females. They are most common in warm countries although some species occur in temperate zones. The Velvet-wasps are mainly parasitic on ants, bees and other wasps, but the Flower-wasps, so called because of the way they frequent flowers, burrow into the ground to lay their eggs upon beetle larvae.

In the Hairy Flower-wasps, the largest of all, both males and females are winged, as is the case with all remaining wasps to be considered. Like the Flower-wasps they lay their eggs on the larvae of other insects, but since many species seek out the larvae of particular insects for this purpose, it has been possible to use them in the control of pests.

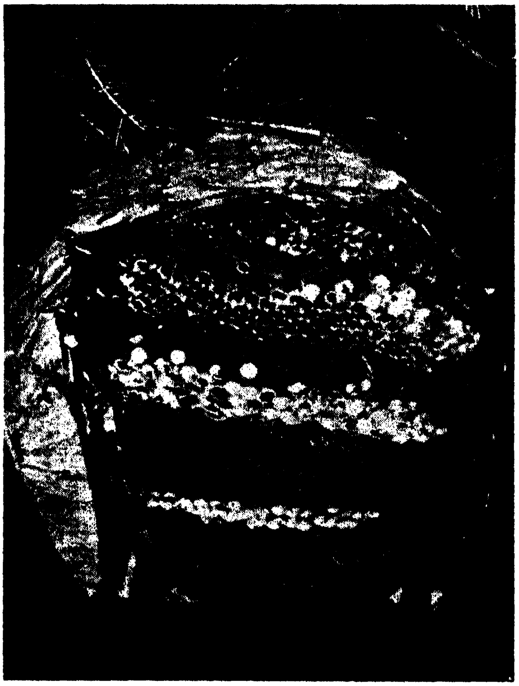


Front view of the head of wasp, much enlarged, to show the large compound eyes, the antennae and the jaws, with the tongue protruding.

From the habit of the Hairy Flower-wasps, of laying their eggs on caterpillars, it is but a short step to the Sand-wasps which first dig holes to bury their victims before laying eggs on them. This tendency is taken a step further in the Mason-wasps, which fashion clay-pots in which to store the food for their progeny, and ends in the Social-wasps, with their colonies living in nests of paper.

A queen and a worker of the North American Yellow Jacket wasp, to show how much larger is the queen.

The Sand-wasps, or Spider-hunters, dig pits in the sand, and in them store the bodies of spiders. They lay their eggs on the spiders and seal up the pits, leaving the grubs to feed on the spider-carcases. Some Sand-wasps are more than three

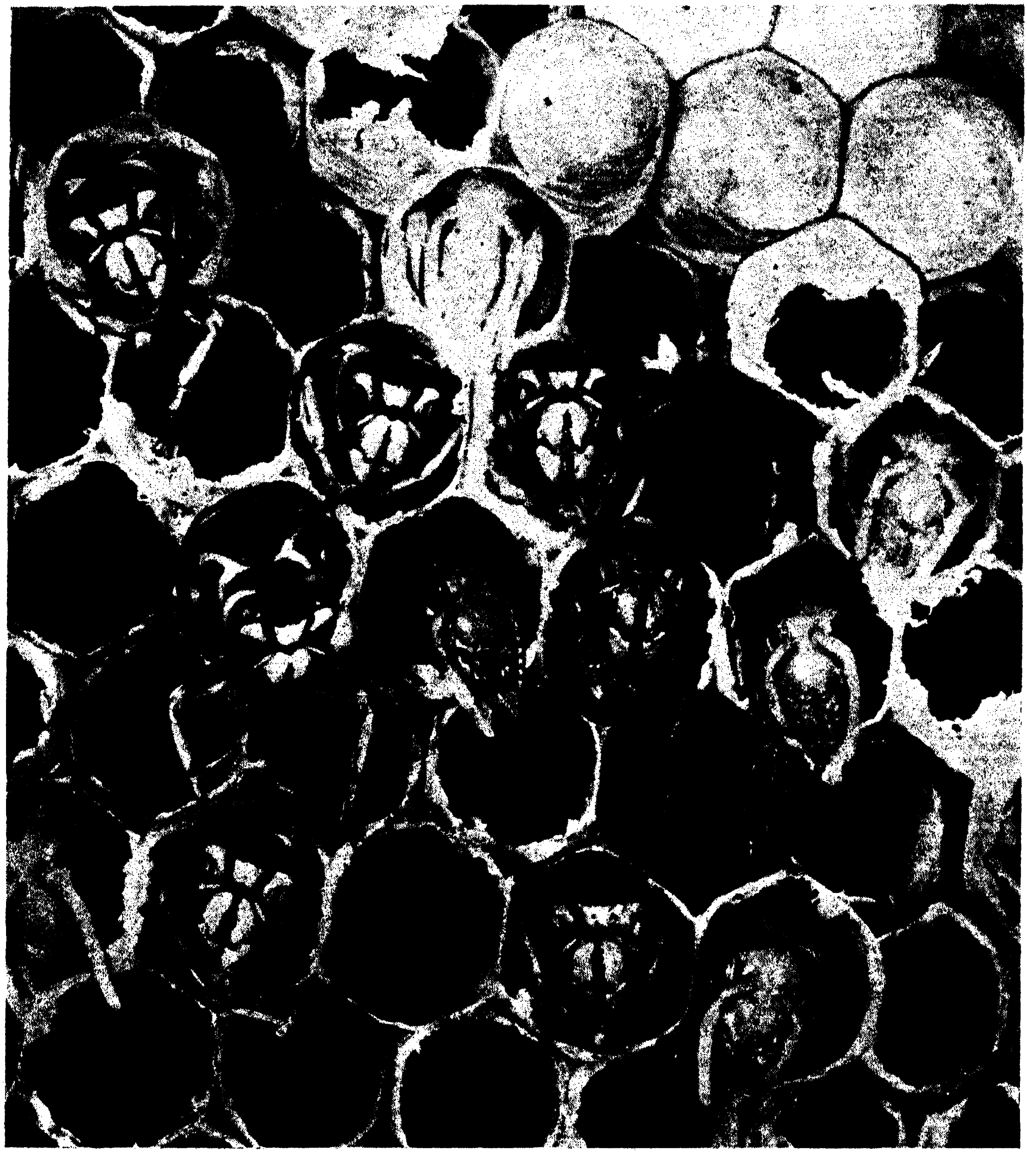


The nest of the Yellow Jacket wasp, with one side cut away exposing five tiers of cells.

inches long and choose as their victims the large, so-called Tarantula spiders.

The Mason-wasps, also called Mud-daubers or Potter-wasps, build nests of clay. These may take the form of a single pot or jug, attached to a stem or the surface of a leaf, or hidden in a hole in a stem; or they may consist of a number of tubular cells fastened together, each containing a larva and a quantity of stored food, caterpillars or spiders, paralysed by being stung. These multiple nests are built under beams or rafters, under stones, or in almost any nook or cranny in a building.

The Social Wasps build nests of paper made by the workers from weathered surface of wood, and these nests are suspended in trees, or from the roots of trees in underground chambers. The nests are usually spherical and composed

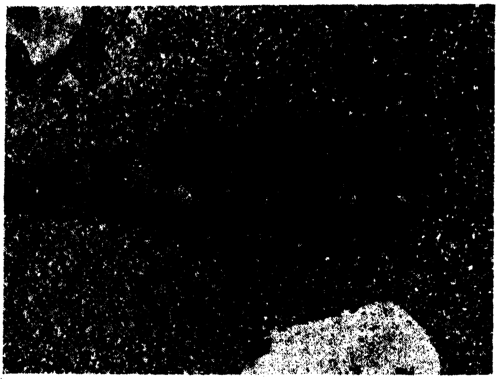


Young Paper Wasps emerging from the cells in which they have developed from the larval stage into the fully-grown wasp.

Nest of a tree wasp, with the entrance below.

of horizontal layers of cells, each cell with a single larva, the whole being enclosed in an outer envelope. The colonies consist of males, females or queens, and workers, the last-named building and maintaining the nest, and feeding and caring for the young. As in other

A group of cells from a wasp's nest. In some the eggs have just been laid; in others the young wasps can be seen.



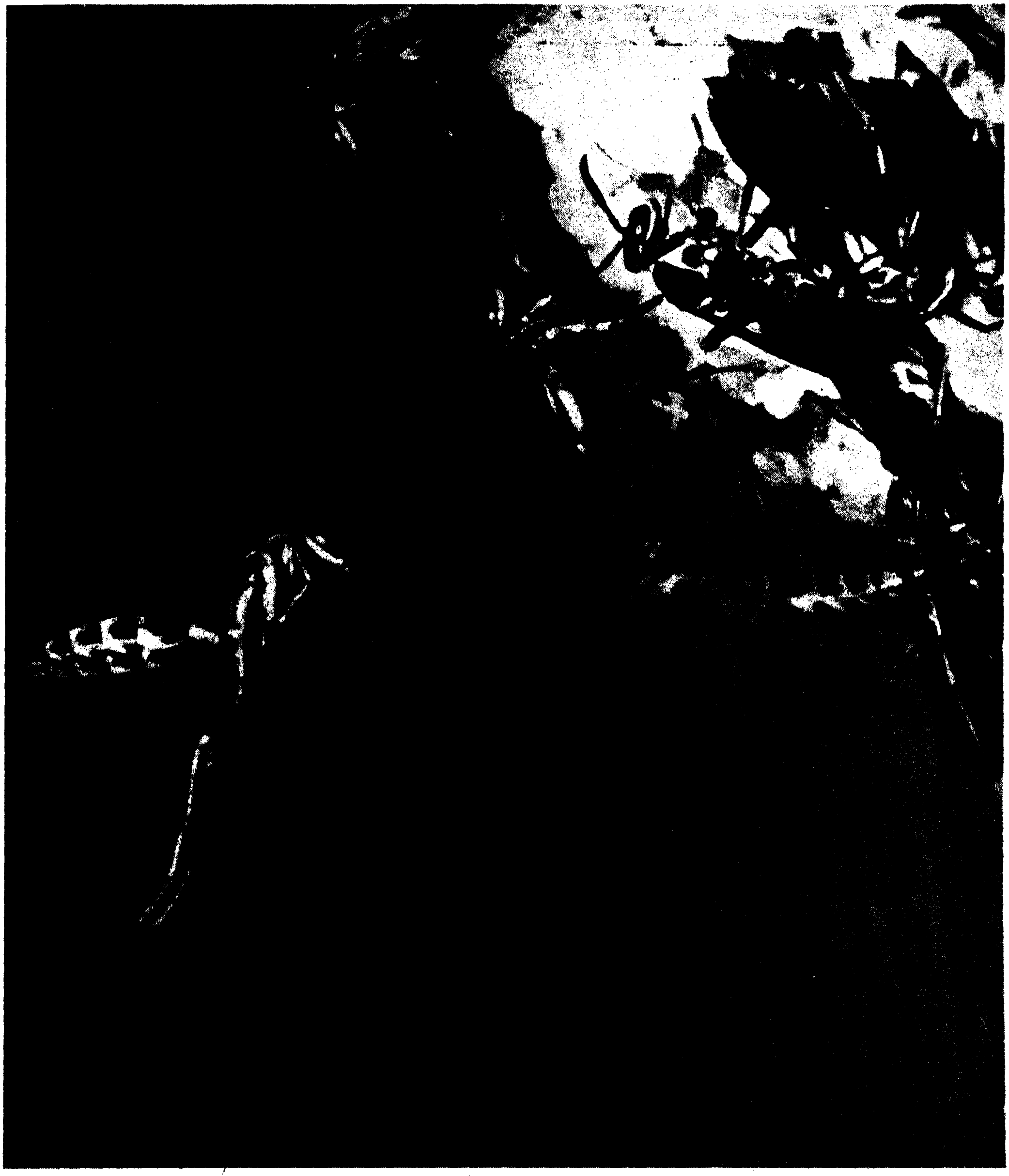
The Sand- or Digger-wasp *(Ammophila)*, sometimes known as the Hunting-wasp, dragging a caterpillar to her burrow, where it will serve as food for her offspring.

wasps, the food is caterpillars and other insects. The Sphecoid Wasps are solitary, excavating their nests in the ground and storing them with living food on which to lay their eggs. Their victims are mainly the caterpillars of moths, although some attack smaller insects, such as plant-lice. This group of wasps is remarkable for the manner in which the victims are killed, by inserting the sting between the segments on the underside of the body so that the poison is injected near the main nerve-ganglia.

Cell of a Paper-wasp, with the side cut away to show the developing wasp inside.

Bees are not so strikingly coloured as the wasps, and are more heavy-bodied than either wasps or ants. Their food is entirely vegetarian, nectar or pollen, and the hind-legs are provided with pollen-baskets. That is, they are broadened and flattened, with a slight depression on the inner sides furnished with rows of hairs for the reception of the pollen. In seeking nectar and pollen, bees perform a great and widespread service in pollinating the flowers they visit, although this service is entirely accidental.

Honey, the product so familiarly associated with bees, consists of nectar that has been swallowed, partially digested and then regurgitated. The grubs are fed by the workers on bee-bread, a mixture of honey and pollen. The wax, used in



A worker wasp in flight, preparing to alight on the nest.

building the nests, and usually associated in our minds with honey, is derived from glands on the undersurface of the body of the young workers.

As in both the ants and the wasps, there are all stages among bees between the solitary and the colonial species, the majority being solitary. The solitary bee makes one cell at a time, provisions it, and lays an egg in it. There are, however, species in which several bees use the same burrow, but use separate cells. In yet other species the cells may be formed together as a simple nest, foreshadowing the more complicated nests of the higher colonial species. In these latter, the individuals forming the colony consist of fertile females or queens, the males or drones, and the undeveloped females or workers. The large colonies persist for years, whereas in the species making the simplest nests the females surviving the winter have to start afresh each year.

Since the social organisation of bees is dealt with more fully below, it will suffice here to deal with unusual types of bee. The leaf-cutting bees make their nests in the ground, in hollow stems or even in rotting timbers. In a cylindrical cavity they construct thimble-shaped cells, wrapped in fragments of leaves, oval pieces being used on the sides with a circular piece sealing the end. As soon as one is constructed, another is built in front of it, so that in the completed nest there are eventually six to eight cells lying end to end. The bee cuts the pieces out by holding the leaf in its hind legs and using its jaws like a pair of scissors.

The Mason-bees construct irregular clusters of

Worker wasps busy on the cells. Some of the cells bear their caps, showing that the developing wasps are still within; some are empty; one near the centre shows a wasp emerging, pushing the cap off with its head.

cells with their walls made of clay or sand. Among the Bumble bees there is an interesting development in which the species of the genus *Psithyrus* parasitise the nests of other Bumble bees (*Bombus*), and are known, in consequence, as Cuckoo-bees. The female *Psithyrus* enters the nest of the *Bombus*, kills the queen, takes control of the colony, lays her eggs and has the grubs fed and tended by the *Bombus* workers. Although *Psithyrus* is degenerate, having lost among other things its pollen-baskets, yet it is so like the *Bombus* in size, colour and general appearance that the deception passes undetected by the *Bombus* workers.

THE SOCIAL HABITS OF INSECTS

by

GILBERT NIXON, B.A.

It is commonly believed that ants, bees and wasps are social insects. While this belief is true of ants, the number of species of bees and wasps with social habits amounts to no more than a small fraction of all those known to entomologists. But wherever the habit of living in societies does occur in these three groups, it often shows a complexity which, if the White

A queen wasp, on the right, laying her eggs.

Ants or Termites be excluded, is without parallel in insect-life.

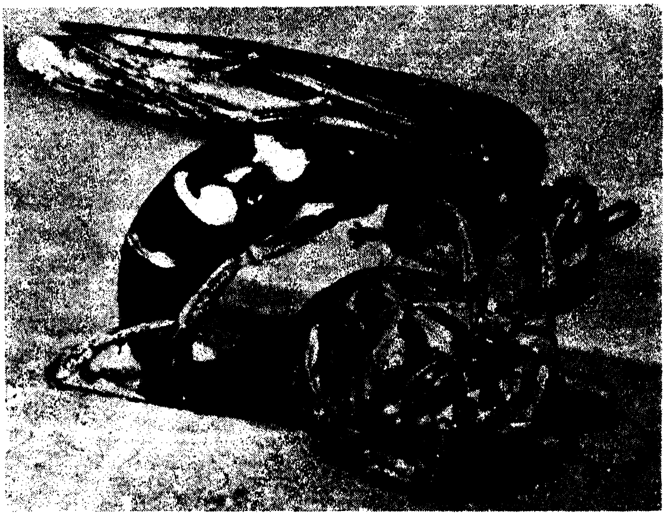
The term 'social' as applied to Hymenoptera indicates that a number of individuals live together in a closely integrated society and that these individuals are in a varying degree mutually dependent upon one another.

In the simplest type of society, as in the African wasps of the genus *Belonogaster*, several females join forces, build a common nest and take an equal share in the care of their offspring. Here there is no division into queen and workers, all the females being physiologically equal. In its most highly developed form the pattern of social life becomes more elaborate and the female members of the community tend to be divided, often very sharply, into two castes consisting of one or more fertile females called queens and numerous sterile females who function as workers. These workers, the daughters of the queen in monogynous societies, cannot be fertilised by a male and have no reproductive life of their own. They behave as though chained by instinct to the community to which they

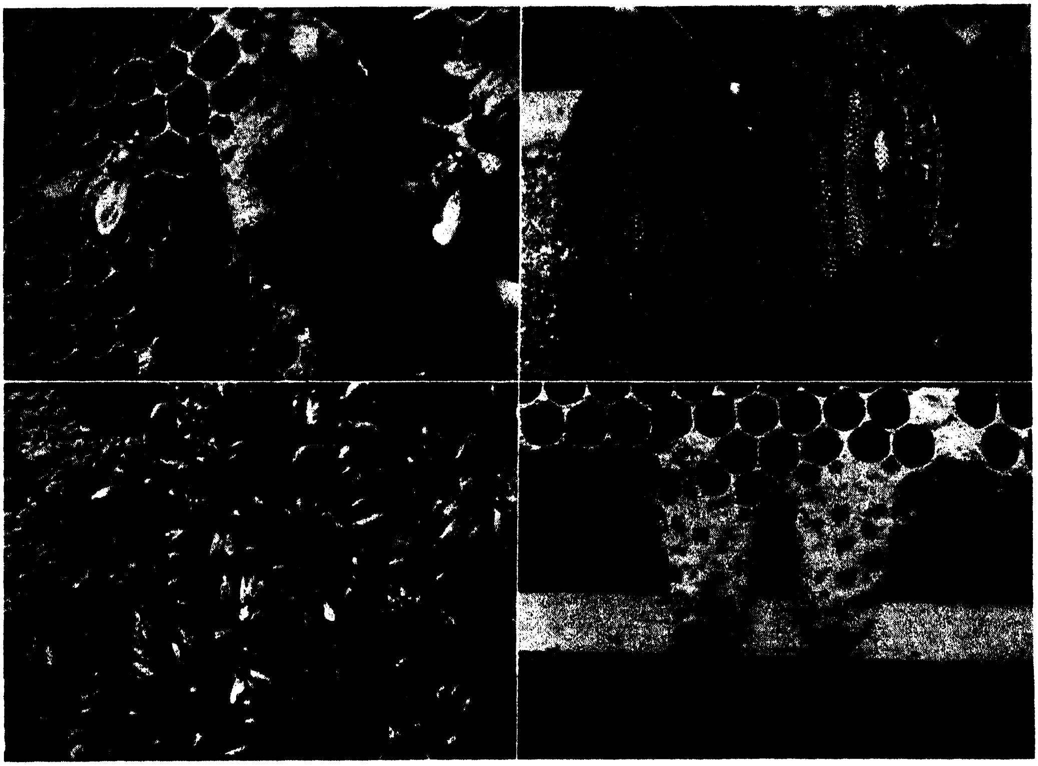
A worker wasp feeding on a water-melon.

belong and labour unceasingly in its service. It is believed that a certain deficiency in diet during the larval period is responsible for their sterility. They are, so to speak, subjected to a kind of nutritional castration.

The difference between worker and queen may be little more than a difference in function correlated perhaps with a difference in size as in the Bumble bees (*Bombus*). Or it may be



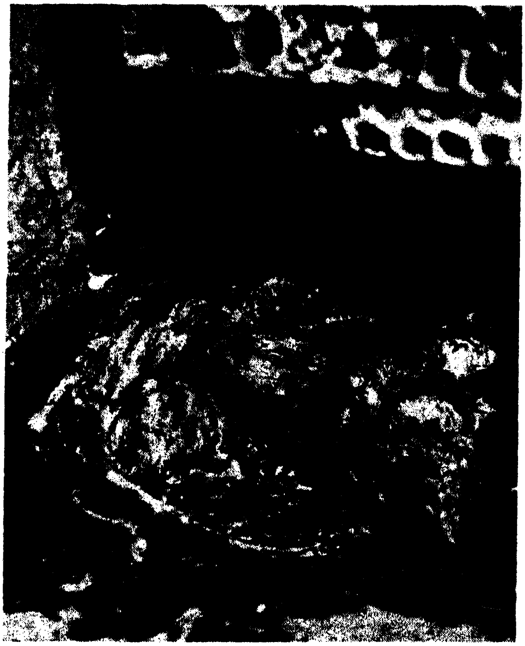
Some insects have a most unusual way of feeding their young. The Cicada wasp captures a Cicada and stings it just enough to paralyse it, so that the insect still retains life. Then she lays her eggs on the Cicada and when the larvae hatch they have fresh meat to eat.



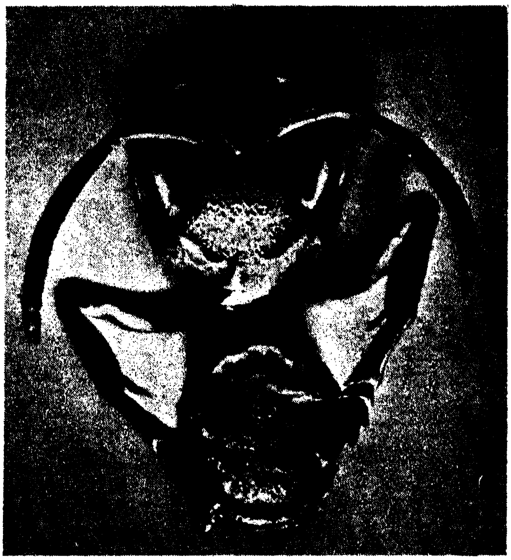
A piece of waxen comb, top left, showing worker cells from some of which the bees have not yet emerged. In the centre are two cells from which queens have just emerged, the one on the left showing the lid pushed back to permit her to make her exit. Should the queen die some of the worker grubs, not more than three days old, are fed with royal jelly so that they may grow into young queens, one of which will eventually lead the colony. An old-fashioned skep, top right, for the honey bee, filled with comb. Bees on a comb, bottom left. A piece of comb showing two queen cells, bottom right.

so exaggerated that queen and sterile daughter could hardly be thought related, as in the African ant *Carebara*. The queen *Carebara* is a huge ant about one inch long whereas her workers are minute insects, quite unlike their mother and less than one thousandth part as big. In many kinds of ants, especially the tropical genus *Pheidole*, the worker caste is subdivided into simple workers and others with enormous heads called soldiers. The rôle of the soldiers, however, is not merely defensive; the huge head accommodates powerful muscles which give great strength to the ant's mandibles, enabling it to crush seeds and hard insects.

The typical community consists then of a queen, numerous workers and at certain periods of the year large numbers of males. Its whole activity, whether the society be of ant, wasp or bee, usually culminates annually, at least in temperate regions, in the production of a large number of sexual forms that is—young queens and males. On fine days these sexual forms leave the nest for mating, after which the fertilised females are ready to become the foundresses of new colonies, though usually only after they have passed the winter in some place of concealment. Such is the habit of the Bumble bees (*Bombus*) and the social wasps (*Vespula*) of Europe and North America.



A mouse visiting a hive has been stung to death by bees and its body embalmed with the resinous substance used by bees for plastering cracks in the hive.



Intimate portrait of a hornet.

A hornet (*Vespa crabo*) has crawled to the end of a twig and is peering into the lens of the camera. The photograph shows how unlike is the face of an insect to the faces with which we are more familiar. In addition to the two large compound eyes at the sides of the head, there are three small, simple eyes on the top of the head. The sense of smell is lodged in the antennae, in hundreds of minute pits scattered on each joint.

After the single act of copulation, for the queen mates only once in her life, the sperms that enter her body are stored in a special organ called a spermatheca. Here they continue to live, vast numbers of them, ready to be used by the queen whenever she needs to lay eggs. She can lay fertile eggs throughout the whole of her life, which in the case of *Bombus* and *Vespula* is one year, but in *Apis* (the Honey bee) may extend to five years and in some ants even longer. A queen ant has been recorded as living for fifteen years in captivity.

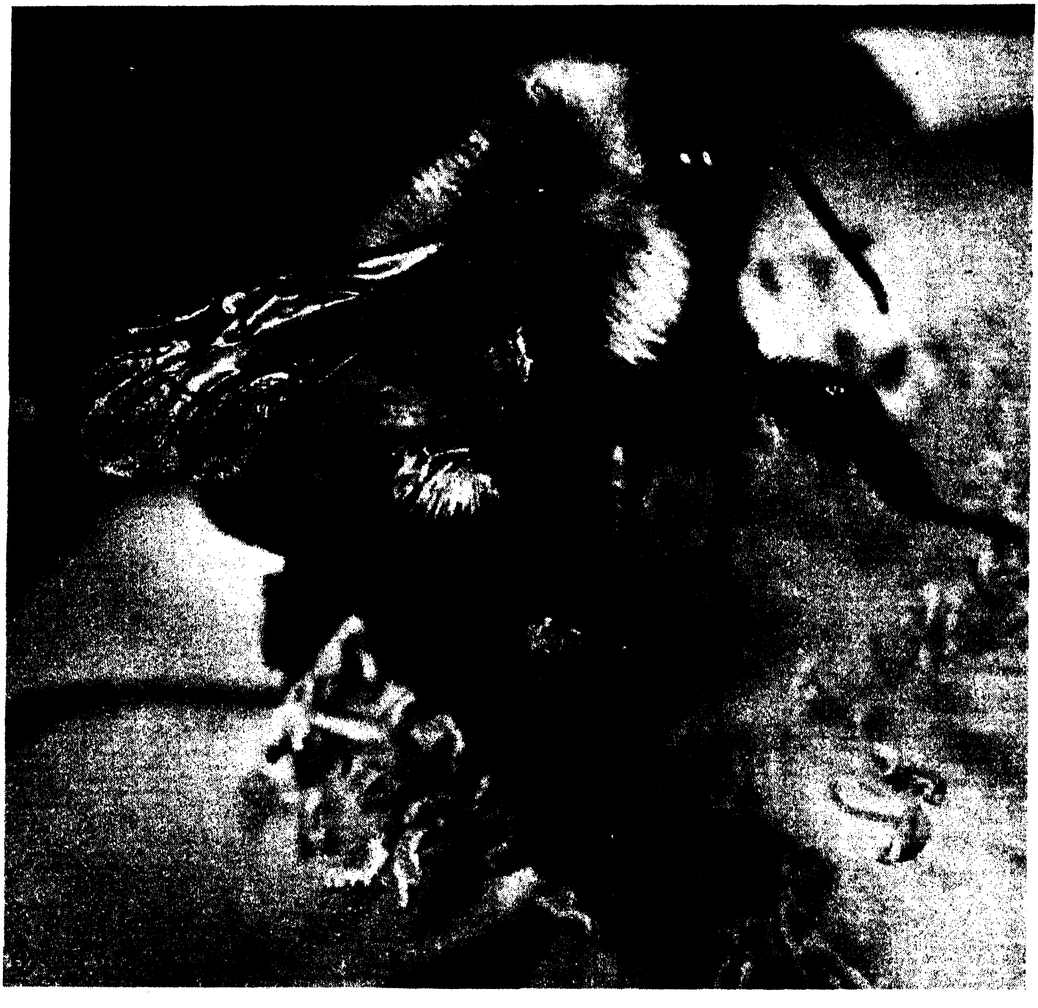
The colonies of the Bumble bees and the social wasps (*Vespula*) are annual, being started by the overwintered females in the spring and breaking up at the end of summer after the sexual forms have left the nest for pairing. The social life of these two groups of Hymenoptera is similar in the sense that the queen differs from the workers only in size, though this difference is not always well marked in *Bombus*, and in her ability to lay fertile eggs. She is able to build a nest, forage for food and rear a brood of workers. During the initial stages of establishing their colonies, the queen Bumble bee and the queen wasp are completely independent.

How different is the queen Honey bee (*Apis mellifera*)! Degenerate in structure, for she has a shorter tongue than the workers and lacks the pollen-carrying basket on the hind legs, she is unable to lead an independent existence and, except for the short flights she makes before finally meeting and pairing in the air with a drone, is never out of the company of the workers.

The feast is on. Here we see a Paper-wasp hanging head down from a branch by its back feet. The wasp will hang in this position until the fly (which is the unfortunate victim) is no more.

The type of community that occurs in *Apis* is intimately linked up with the restriction of function of the queen and is outstanding in two respects; first, the degeneracy of the queen and her inability to found a colony unaided has led to the phenomenon of swarming, and, second, the ability of the *Apis* colony to maintain itself over a number of years is dependent upon the worker's deeply fixed instinct to store the nectar of flowers and convert it into honey.

Apis mellifera shows very well what an important rôle food-supply plays in the economy of the social Hymenoptera. Although the carnivorous wasps, *Vespula*, do not store food in their combs, they have nevertheless solved the problem of food storage in a novel way. When a wasp in its nest wants food, it goes to one of the open cells containing a growing larva and by gently biting the head of this larva, stimulates it to eject from its mouth a droplet of fluid—a tit-bit which the wasp greedily swallows. Fortified with nourishment, the worker wasp sallies forth in search of fresh food for the larvae. It is only when the larvae are well fed that they are able to secrete the fluid so eagerly sought after by the workers. Thus the advantage is a mutual one and may be regarded as an essential component of the social life of *Vespula*.



A Bumble Bee gathering pollen, which is stored in pollen-baskets on the hind legs.

A swarm of Bees (*Apis dorsata*) in the Dutch East Indies, readily recognised, in life, by their fawn-coloured abdon

Almost as vital for the successful development of the colony as this exchange of food between larva and worker is the power the workers have of regurgitating food stored in their crops and passing it from one to another. The habit is best developed among wasps and ants and ensures that whatever food comes into the colony is evenly distributed among its members.

The ants, too, adapted as they often are to a harsh environment, have guarded themselves against inevitable food-shortages in interesting ways. By gathering the seeds of plants during the short season when the desert flowers, the Harvesting ants (*Pogonomyrmex*) of the North American deserts are able to maintain themselves when other kinds of food are scarce. Even more remarkable are the habits of *Myrmecocystus hortideorum*, known popularly as the Honey-pot ants. The workers of this species set aside some of their sister workers and feed them lavishly with whatever sweet juices are available until they become living reservoirs of food. With their abdomens enormously swollen, these repletes, as they are called, hang motionless from the roof of their underground chambers, waiting to be tapped, like so many barrels of wine, when other sources of food have dried up.

Colony founding in Hymenoptera is not always as straightforward as in *Vespula*, *Bombus* and *Apis*. Although the queen Honey bee is a step behind the queen Bumble bee and the queen wasp in that she has lost the ability to found her colony without help, she still needs to rely on her own species to become the head of a new colony. In other kinds of social Hymenoptera, especially among ants, the loss of independence in the queen has forced her to live either as a temporary or permanent parasite on other species. For instance, the queen of the Slave-maker, *Formica sanguinea*, sets up a home by stealing pupae from the nest of another ant, *Formica fusca*. When the *fusca* workers emerge, they rear the worker brood of their foster-mother. The *sanguinea* workers inherit their mother's urge to make slave raids and they, too, pillage and plunder the nests of the timid *Formica fusca*. But slaves are dispensed with when their colonies become sufficiently populous.

Permanent parasitism has been reached by *Anergates atratulus*, a European ant, in which the female, no longer to be styled queen, has become completely degenerate. She produces no worker caste and must ingratiate herself into the colony of another species of ant, *Tetramorium caespitum*, to complete her life cycle. When once the *Tetramorium* workers have accepted her, they kill their own queen, destroy their brood and devote themselves to rearing the progeny of the usurper.

CHAPTER XXII

THE INSECTS VI

SUB-CLASS – ENDOPTERYGOTA

The Diptera, or two-winged flies

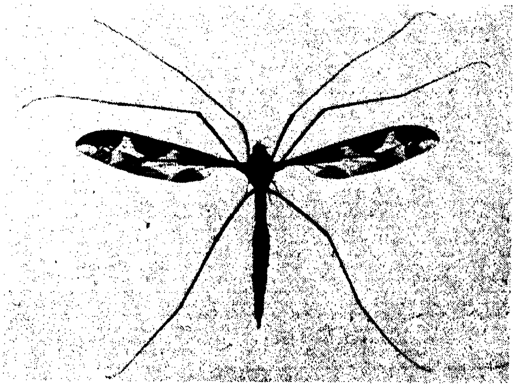
THE members of this order, except for the few that are entirely wingless, have a single pair of delicate membranous wings, and behind them the remains of a second pair converted into thread-like structures knobbed at the ends, called halteres. These are balancing organs, and also organs of hearing. The mouth parts are modified for piercing and lapping. The larvae are usually referred to as maggots, soft-bodied grubs living in decaying matter or in living tissues, although where the larvae are aquatic, as in mosquitoes, this name is not used.

The order contains, probably, a quarter of a million species of very diverse habits. Altogether it is a difficult group to deal with and in this account attention will be concentrated on the more familiar or outstanding examples.

Most of the Diptera lack the showy colours of such insects as butterflies or beetles; nor have they any obvious merits so far as man is concerned; for these reasons we think of them in terms of disgust and displeasure. It is true that the members of this order affect the lives of men more than those of any other group of insects, and to a large extent they do so adversely, yet there are some ways in which they are beneficial.

It will be both interesting and profitable to consider in some detail the exact significance of the activities which we refer to as beneficial or injurious to man. The use of these phrases, in the first place, is due to man's idea that he is the centre of the living world and that the rest of creation is intended either to serve his purpose or to work against him. Only by abandoning such a notion and getting a true perspective can we hope to see the world of living things with a balanced vision.

The Diptera constitute the youngest group of insects, yet even they have an ancestry dating back some two hundred millions of years, and they were as flourishing as they are to-day fifty million years ago. They were well established on the earth, therefore, before even the mammals appeared—and man is a latecomer among mammals. The way they live and behave has no direct relation to what man thinks or does, except in so far as man has sought to harness the whole world to his own selfish purpose.



A large Daddy-longlegs *(Tipula gigantea)*. It is not easy to see what use its long legs serve, or why they should break off so easily.

If a particular species of fly feeds upon the fruit we grow for our own use, and thereby is classified as a pest, it is as well to remember that this fly was feeding on such fruit long before man domesticated and cultivated it. To us the fly is a pest; to the fly man is a nuisance. Similarly, the maggots in the manure heap or the rotting carcase may repel or even disgust us, but they are merely carrying on the work performed by generations of their species, scavenging. As to the blood-sucking habit, this probably started with flies feeding on the juices of plants and the transition from this to sucking the juices (i.e. blood) of animals would follow naturally. An extension of this habit, which may be called an intermittent or temporary parasitism, has led to certain flies losing their wings and becoming permanent parasites, as in the Tachinidae.

The debit sheet standing to the account of Diptera, so far as man is concerned, has, however, become a long and serious one. There are the pests on crops, like the carrot-fly, the clover midge, or the Hessian fly of North America which is responsible for millions of dollars worth of damage each year. There is injury to cattle, as with warble-flies, horse-flies, blow-flies and, that scourge of Africa, the tsetse fly. There are the flies that cause annoyance or bodily injury to man himself, sweat-flies, midges, or those the larvae of which infest the skin, causing boils, or infest wounds. Finally, there are those which transmit disease, such as African sleeping sickness, malaria, yellow fever, typhoid, and a number of others.

The antennae and mouth of the male *Culex*.

On the credit side, there are many species of Diptera that assist in pollinating fruit and other crops, or destroy weeds, or parasitise other noxious insects, and last but not least those many that act as scavengers.

There is sufficient uniformity in het Diptera to make it unnecessary to do more than describe briefly some of the familiar examples, together with a few less well-known.

The Crane-fly, family Tipulidae, has a long slender body, narrow wings and very long legs, which make it look like an overgrown mosquito. The adults are found in damp, weedy places in late summer. They are feeble and ungainly in flight, and even more awkward when walking. The larvae are scavengers, those of some species living in water, others in mud or in soil, feeding on vegetable debris, though those living in soil, the well-known leather-jackets, are injurious to the roots of grasses and cereals.

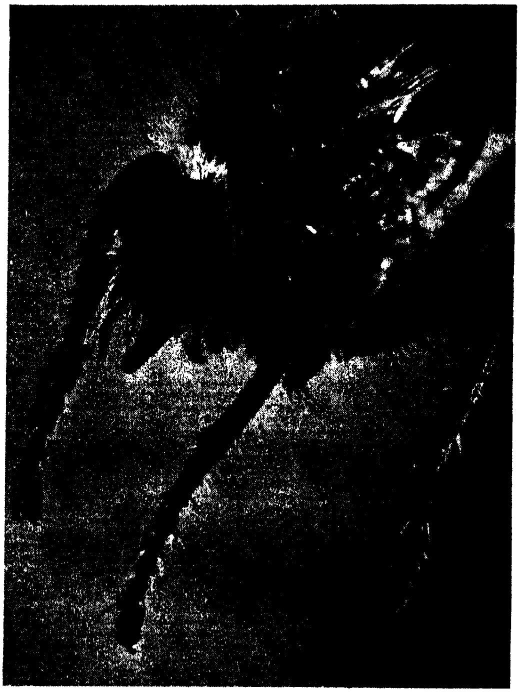
Mosquitoes need no introduction, for although the males live by sucking the juices of plants, the females, which probably did the same in the first place, have taken to feeding on blood and, in fact, cannot become fertile without doing so. Although the bite is troublesome, it is more as a carrier of disease that the mosquito is to be feared. Malaria, yellow fever, dengue fever, elephantiasis are all transmitted through the bite of the mosquito, and as a commentary on this it may be recalled that malaria claims more victims than any other single disease, and that the building of the Panama Canal was not possible until a way had been found of dealing with the ravages caused by mosquitoes.

Eggs are laid on the surface of water, typically in groups or rafts, and almost any stagnant water may have its quota, whether in pools, ditches, in hoof-prints, cavities in trees, water butts, or in the standing water in a derelict tin can. The eggs hatch in a day or two, and the larvae feed on organic debris, coming to the surface to breathe through a special tube at the tip of the abdomen. In a week or two these pupate, the pupae swimming about for a few days before the imago appears.

Protection against mosquitoes, apart from the use of nets and screens for personal comfort, and the use of deterrents of various sorts, is obtained by draining away standing water, by putting oil on the water or by the use of certain fish which feed on the larvae.

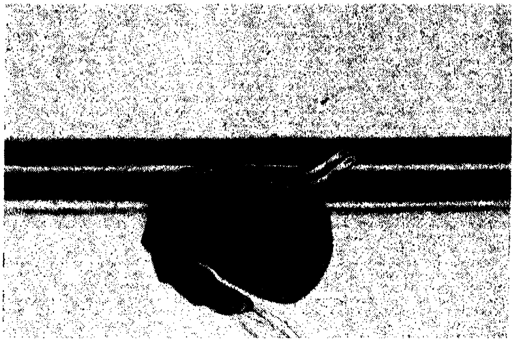
There are three main types of mosquito to be noted. *Culex*, often called the common house mosquito, is not harmful except for the discomfort of its bite. Members of this genus can be recognised by the horizontal position of the body when at rest. *Anopheles*, the carrier of malaria, when at rest has the body tilted upwards, the head lowered. *Aedes*, responsible for transmitting yellow fever, has the legs banded in black and white.

The eggs of some species of *Aedes* are said to be able to live for 10 years or more, an obvious advantage for species which may have to tide over long periods of drought in desert regions. Whenever rain comes the eggs are washed into pools and hatched, the development to the adult proceeding rapidly. All such eggs must be capable of withstanding a high degree of desiccation, and they are accordingly provided with very thick shells.



A mosquito with short antennae. The sucker-like pads on the last joints of the legs enable it to walk on a ceiling.

The most noticeable difference between male and female mosquitoes is that the antennae of the former are markedly plume-like, while those of the female are usually less elaborate. The mouth-parts of the female are piercing, those of the male are not.

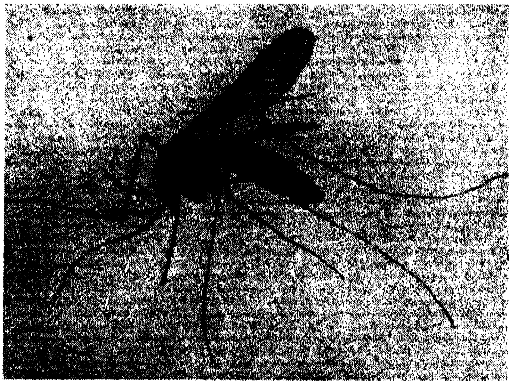


The pupa of *Culex* breathing at the surface.

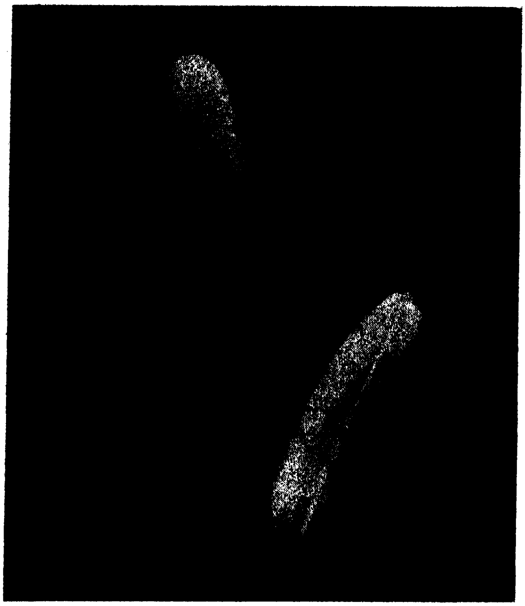
A group of flies which have assumed a considerable importance in recent times is that known as the Fruit-flies, belonging to the genus *Drosophila*. These are minute, an eighth of an inch long, with yellow bodies and red eyes, whose larvae feed on ripe or rotting fruit. Since they breed and grow rapidly, producing a generation in 8 to 12 days, and are easy to keep, they have become favourite subjects in the study of Genetics, that branch of biology which deals with heredity and variation.

There is, however, one Fruit-fly at least, *Dacus tryoni*, of Australia, which constitutes a serious orchard pest.

The House-fly, *Musca domestica*, which has followed man all over the world, is a serious pest, responsible for spreading such diseases as



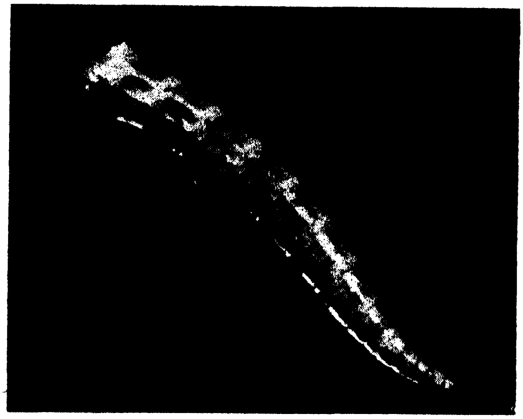
The female mosquito, *Culex pipiens*.



The eggs of the House-fly *(Musca domestica)*.

typhoid, dysentery, cholera, anthrax and possibly others. The bacteria are carried on the hairs of the legs, or possibly are swallowed and regurgitated. One result of the mechanisation of transport, with the corresponding decrease in the world population of the horse, has been a decrease of the house-fly since they prefer to lay their eggs in horse manure, although decaying vegetation can be used for the purpose. This fly, the most abundant and familiar of insects about human habitations, is found in all habitable parts of the world, and the most obvious method of control is to keep at a minimum the amount of decaying organic matter left lying about.

The female house-fly can lay 500 eggs, white, oval and about one twenty-fifth of an inch long. These hatch in 24 hours giving rise to legless maggots which feed on organic matter, and the development from the egg to the adult takes place in two weeks, although in fine weather hatching may take place in a few hours, the adult stage being reached in ten days.



The larva of the House-fly.

Pupae of the House-fly.

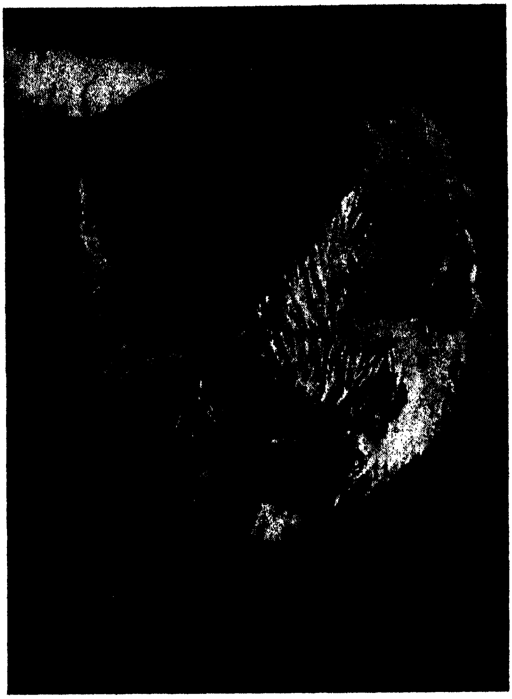
In the autumn the house-flies die off, many of them being killed by a fungus, but a few overwinter in crevices.

Related to the House-flies are the Stable-flies, capable of biting, and the Blow-fly, which lays its eggs in carrion and in doing so acts as one of the best scavengers, a virtue which the householder fails to appreciate when applied to the family meat supply. They also infest wounds and sores, a behaviour which recent research has shown to be beneficial. Blow-flies are widely distributed in many parts of the world, and are known as Bluebottles or Greenbottles on account of their metallic colours. Another relative is the Tsetse-fly, the transmitter of African sleeping sickness.

Bot-flies produce larvae parasitic on mammals. One, *Gastrophilus equi*, is yellowish-brown, about half an inch long, and lays its eggs on the hair of the shoulders, belly and legs of the horse. The eggs are licked off and swallowed. They hatch into maggots, or bots, supplied with rows of hooklets by which they attach themselves to the lining of the stomach. With a heavy infection the digestion of the horse suffers. The fully mature larvae pass out in the excreta and pupate in the ground.

The larvae of the warble-flies, of the family Oestridae, live under the skin of cattle and sheep. The eggs, again, are laid on the legs and feet of the quadrupeds and are licked off. The subsequent behaviour is, however, different from that of the bot-fly, since the larvae bore through the internal tissues to reach the skin, where they form tumours, known as warbles. The sheep bot-fly (*Oestrus ovis*) lays its eggs in the nostrils of sheep. One species of bot-fly, of tropical America, lives under the human skin, and another in the stomach.

The partial parasitism seen in the bot-flies is carried a stage further in the Sheep Tick, or Sheep house-fly, which is wingless and has the abdomen swollen, giving the animal the appearance of a tick. These flies are viviparous, the young being glued on to the wool of the sheep, where they form reddish-brown pupae. The adult stage is reached in about three weeks.



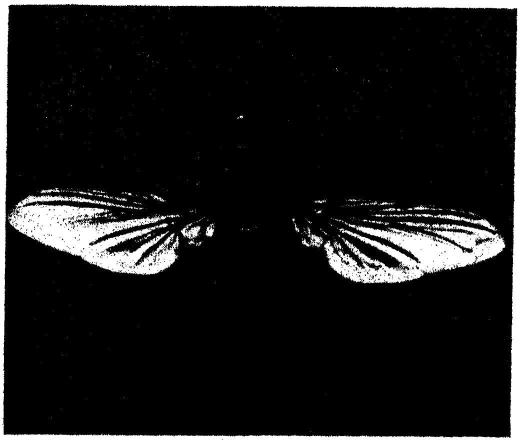
The face of a Bluebottle.

A House-fly emerging form the pupal case.

A Hover-fly visiting a flower for its pollen.

The mouth-parts are both biting and sucking, but although they cause irritation to the sheep they are not injurious.

The Robber-flies, highwaymen of the insect world, lay their eggs in the ground, where the larvae live by burrowing and feeding on earthworms and the grubs of other insects. This stage may persist for three years, a larval period reminiscent of that of the may-flies and dragonflies and in striking contrast with the short period of development required by most Diptera. The adult, which lives for about a month, is an inch long with a lean, slender body, strong legs and wings. It is swift in flight and is able to carry other insects, its victims. The body, which is covered with a layer of hairs, includes a pair of large eyes and a slender neck so that the head can be turned in all directions. The Robber-fly catches bees and wasps in mid-air, carries them to a plant and comes to rest, piercing the armour just behind the head. Then it proceeds to suck out the juices, leaving only the empty skin.



The Common House-fly.

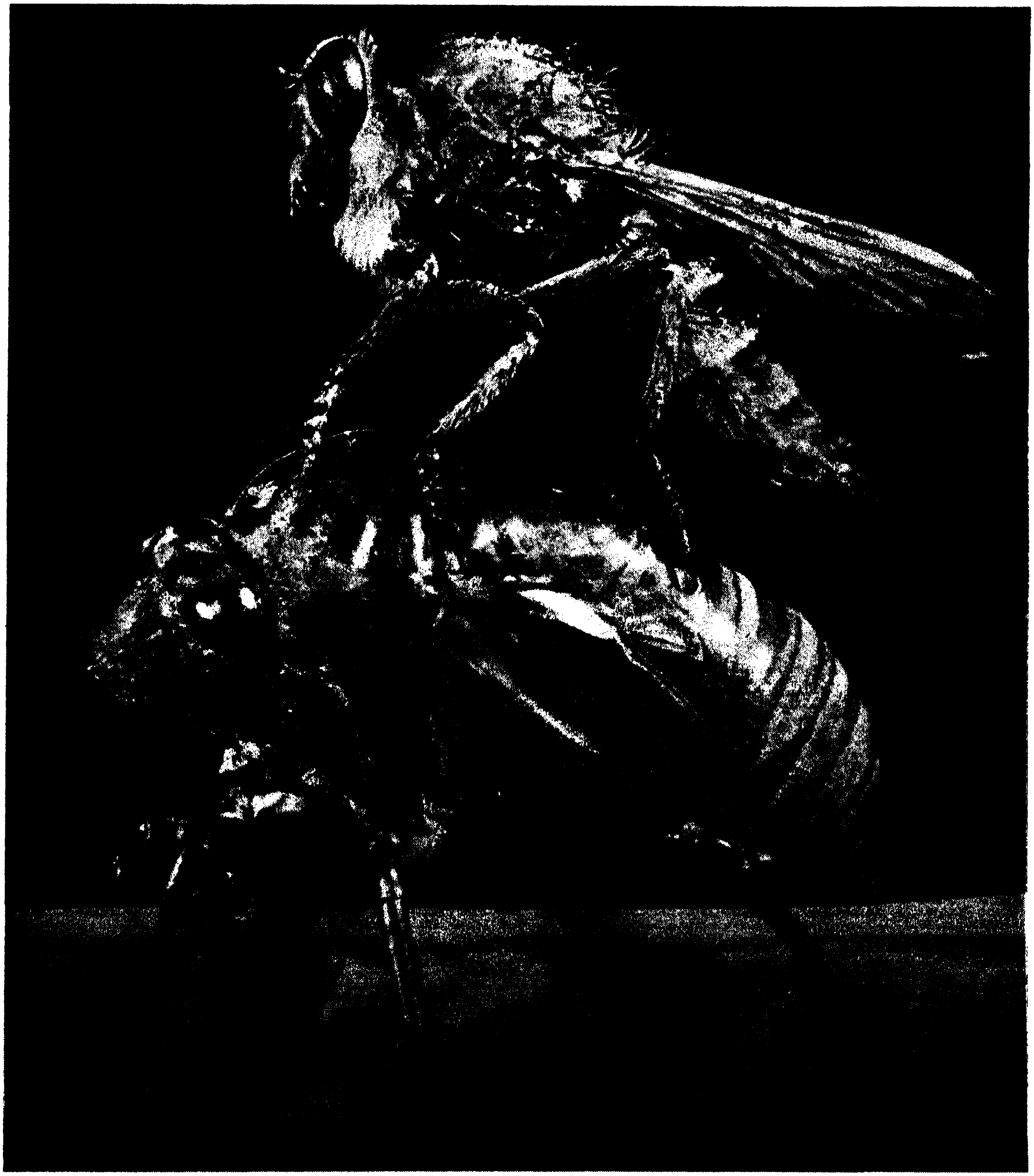
The face of a Horse-fly.

Some unusual habits of Dipterous flies

The pupa of a fly, *Ephydra hians*, found in Oregon and California, was used as food by the local Indians. The fly lays its eggs in salt or alkaline lakes, and the pupae are usually attached to solid objects under water. When there is a storm, immense numbers break loose and are thrown up in great heaps on the shore. Before they were more or less exterminated in the latter part of the last century, the Pah-Ute Indians used to collect large quantities of pupae and, after rubbing off by hand the hardened larval cuticle in which the pupa is formed, they ground them into a kind of flour called "Koo-chah-bie", which at certain times of the year was one of their chief sources of protein.

The petroleum fly, *Psilopa petrolei*, is the only insect which lives in petroleum. The larvae, 7-10 mm. long when full grown, are found in California in the crude oil or petroleum which oozes out of the ground to form little pools, and also in pools near refineries and oil tanks. They feed on other insects which fall into the oil and die. The perispiracular glands are remarkably adapted to this unusual habitat in that they secrete a substance over the setae around the spiracles that enables them to resist the entry of oil.

Certain nematodes which are most severe pests of man in tropical and subtropical countries can



A Robber-fly capturing a Cicada larva.

Accidental cannibalism — a Robber-fly capturing one of its own species.

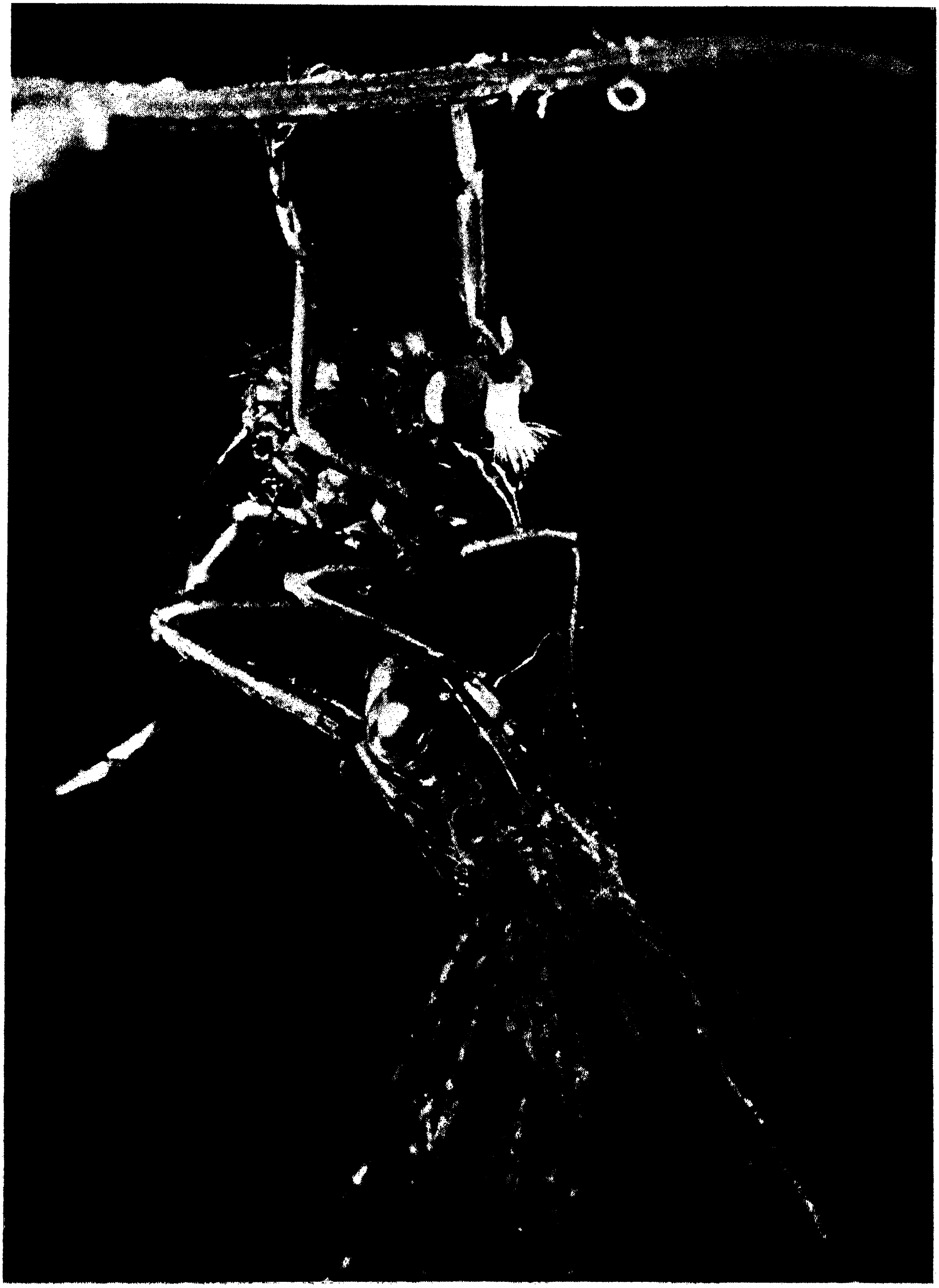
only attack him through the agency of various mosquitoes, which are obligatory intermediate hosts. One of these (*Wuchereria bancrofti*) is the causal organism of a dreaded disease called elephantiasis owing to the swelling, sometimes to an incredible size, of various parts of the body to which lymph or chyle is diverted by the blocking of the usual lymph channels by the filaria *Wuchereria*.

The adult nematodes lay living embryos (called microfilaria) enclosed in a delicate sheath. These are carried to the peripheral blood system whence they are sucked up by mosquitoes. The embryos cannot free themselves from the sheaths in which they are enclosed except in the gut of the mosquito. The reason seems to be that a few hours after the mosquito has sucked the blood it becomes a sticky mass that holds fast to the sheath of any embryos present, so that they can easily slip out of them like a foot out of a mired boot.

The microfilaria have a periodicity which appears to be correlated with the habits of the mosquito. In the American tropics, the chief transmitter is *Culex fatigans*, which bites only at night. It has been shown that the embryos are only present in the peripheral blood stream at night, perhaps because they are only laid then by the adults and are rapidly eliminated by the kidneys. In Oceania, where the principal transmitter is *Aedes egypti*, a day-biting species, there is no periodicity and the microfilariae are found in the peripheral blood system in the daytime.

The African eye-worm, "Loa loa" is closely related to *W. bancrofti* but it is transmitted by a very different fly, *Chrysops* (known locally as the mango fly). This fly bites only in the daytime, and the microfilariae appear in the peripheral blood system only in the day-time, disappearing at night.

Dermatobia hominis, sometimes called the human bot-fly, is found throughout tropical America. It occasionally attacks man but more often cattle, dogs, and pigs. The adult fly is bluish and about the size of a blow-fly. The way in which the larvae gain access to man and animals is one of the most remarkable and unusual adaptations known in nature. When ready to lay, the females captures a large mosquito of the genus *Psorophora*, occasionally another insect, and glues her eggs on the underside of the abdomen of the captured mosquito by means of a quick-drying cement. The *Psorophora* actively seek out human beings or warm-blooded animals from which to suck, and the mosquitoes thus serve as aeroplanes for the rapid transportation of the eggs to suitable hosts. After the eggs are five or six days old they are ready to hatch, and when the egg-bearing mosquito alights on the skin of a warm-blooded animal the maggots receive the necessary stimulus to emerge. It is said that if the young larva in the egg does not have time to emerge completely when the mosquito is biting, it withdraws into the egg



The Robber-fly eats its lunch in a most odd manner, like a man hanging from a trapeze. The fly hangs by its two front legs, the back legs grasping a Dragon-fly. In this position the Robber-fly devours its victim.

shell and awaits another opportunity. After penetration of the skin, the maggots or "screw-worms" require five to ten weeks to develop and grow to a length of a half to three-quarters of an inch. They form large cysts or boils, often excruciatingly painful, which open at the surface of the skin by means of a small pore through which the maggot breathes. When the larvae are fully developed, they crawl out and drop to the ground, where they pupate.

Order Siphonaptera

(Fleas)

The Siphonaptera consists of a small group of some 500 species of insects, secondarily wingless, which are intermittent blood-sucking parasites on mammals and birds. The eggs hatch into small white maggots which feed on the organic matter in dust, whether in human habitations, birds' nests or other places constantly occupied by mammal or bird. In this connexion it is interesting to note that whales, hoofed animals, seals and monkeys which do not have fixed homes, in the sense of a nest or other dwelling place, have no fleas. The maggots of a flea spin a silken cocoon in which to pupate.

The Ichneumon flies lay their eggs in the bodies of other insects, where the larvae feed on and eventually kill their victims. Here is seen the body of a Tomato Sphinx caterpillar with larvae of an Ichneumon emerging through its skin and changing into pupae.

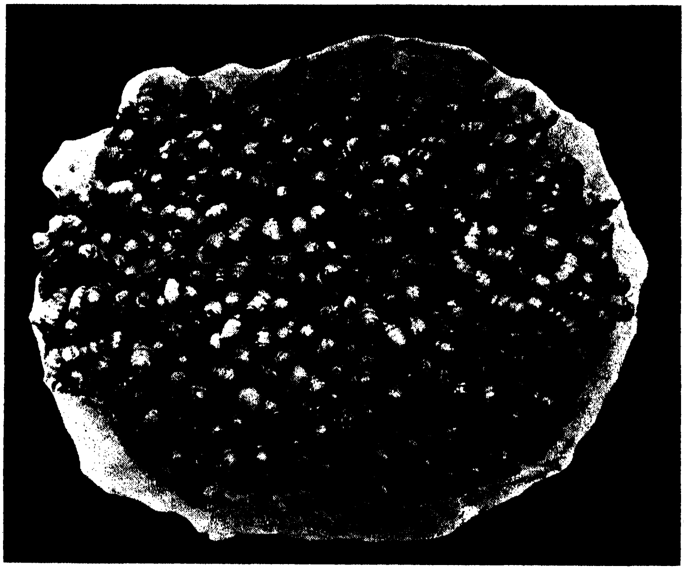
Although some fleas are attached to a particular host, many will parasitize almost any mammal they may come in contact with. The chiqoes or jiggers of tropical or subtropical countries differ from other fleas in that the females burrow into the flesh of their hosts.

Fleas are an important factor in the transmission of disease, particularly those carried on rats.

PARASITISM IN INSECTS

by

GILBERT NIXON, B.A.



Portion of a horse's stomach infested by the larvae of *Gastrophilus equi*. The larvae are bathed in the nutritive fluids of the host and have degenerated accordingly, becoming fleshy and immobile.

Eggs of a biting louse attached to a bird's feather.

The habit of parasitism in its occurrence throughout the animal kingdom involves the idea of one organism living at the expense of another without necessarily causing it any serious inconvenience. No group of animals illustrates this more beautifully than the parasitic worms of which an account has already been given in this book. In the vast world of insects, however, there are very few parasites in this narrow zoological sense. Chief among them are the Bird lice (*Mallophaga*) and the Sucking lice of mammals (*Anoplura*). Other true insect parasites are the notorious bed bug (*Cimex*), and the fleas (Siphonaptera).

Whereas the *Mallophaga* and *Anoplura* pass all stages of their life upon the bodies of their hosts, in insects generally parasitism is only one phase of the life-cycle and is confined to the larval period. The adult is a free-living organism, seeking its food in the vast majority of cases at sources different from those which nourished it as a larva. Parasitism as here understood, where the larvae alone live as parasites, is an extremely common phenomenon of insect life. It has produced behaviour patterns which fascinate us by their complexity and astonish us when we consider by what precarious and elaborate methods they serve the ends of reproduction.

The parasitic insect larva, in common with parasites generally, has undergone degeneration in structure. Seeing that as a rule it lives within the body fluids of its host, where it has no use for organs of locomotion, its legs have either disappeared or become functionless. It has tended to become fat, fleshy, and incapable of movement. In its external appearance it is monotonously smooth and without ornamentation. But against all this it must be said that it is exquisitely adapted to its environment.

The insect parasite nearly always preys upon some other insect. Whatever the host is, almost without exception, it dies as soon as the parasitic larva is full grown. Very often it dies sooner, but when this happens the parasite is equally at home feeding upon its decomposing remains.

All the larger orders of insects contain species of parasitic habit, but by far the majority of such insects are found in the Hymenoptera. Next come the Diptera and last the Coleoptera.

The hosts of the parasitic wasps are very frequently Lepidoptera (Butterflies and Moths). These may be attacked either as eggs, larvae or pupae. The wasp lays its eggs as a general rule either within or upon the body of the host and the larva after hatching may feed as an internal or external parasite. *Apanteles glomeratus* which parasitises the young caterpillars of the Large White butterfly is one of a vast number of species whose larvae develop as internal parasites of their host.

Often the parasitic wasp is itself parasitised by another wasp. For example, some of the chief enemies of the Plant lice or Aphids are small wasps belonging to the genus *Aphidius. Aphidius* crawls among the aphids, laying with swift thrusts of her ovipositor an egg in their unresisting bodies.

Unfortunately the beneficial results of her activities are spoilt because her young are the hosts of another small wasp *Lygocerus. Lygocerus* seems to be extremely skilful at detecting the presence of *Aphidius* larvae in the bodies of the plant lice. Her choice of another parasite as host is an example of secondary- or hyper-parasitism.

Some parasitic wasps do not trouble to seek out their hosts; they merely lay their eggs in a place where on hatching the young larvae can reach the insect in which their development is to be completed. Such a lack of contact between parasite and host reduces of course the chances of survival for the parasite's progeny. In compensation, therefore, the wasp tends to lay a number of eggs proportionate to the risks involved. The position has become almost fantastic in the case of the wasps known as Trigonalids in the early stages of whose life-cycle chance plays such an overwhelming part that very few of the large number of eggs laid by the wasps ever come through to maturity.

Some species of Trigonalids lay up to ten thousand eggs, producing as many as four thousand in one day. Certain species lay them around the edges of leaves where they remain without hatching until swallowed by a caterpillar feeding on the the same plant. Bathed in the caterpillar's digestive juices, the eggs hatch, but before the growth of a young larva can proceed, however, it must enter the body of some other hymenopterous parasite already in possession of the hapless caterpillar. Such a delicate combination of circumstances as that required by the Trigonalid wasps for the fulfilment of their life-cycle is not likely to arise often in nature. Is it to be wondered at that they are not successful from an evolutionary point of view? As individuals they are rare and comparatively few species are known.

Of the Diptera or two-winged flies with parasitic habits the most important family is the Tachinidae. The numerous species are parasitic chiefly upon caterpillars and since some of those selected by the flies are pests of man's crops, the Tachinidae may be regarded as beneficial insects. For example, in North America, the Red-tailed tachina fly, *Winthemia quadripustulata*, frequently destroys fifty per cent of the harmful caterpillars of the Army-worm moth.

Another group of flies of particular interest are the Sarcophagidae. The adults are larviparous, the eggs hatching in the uterus of the female who then deposits the young larvae on the appropriate hosts. As some species happen to be parasitic upon the migratory locusts (*Schisto-*

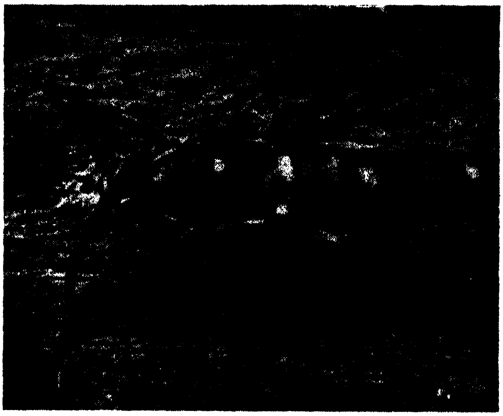
cera) there is a good deal of information about their habits. The method by which contact between parasite and host is established varies according to the species of fly. One species is said to 'squirt' its larva on to the body of the resting locust, while another inserts its ovipositor into the genital opening of the locust and puts a maggot there.

The hairy bee-like flies of the family Oestridae (Warble- and Bot-flies) are important because some of the best known species are parasitic upon mammals. The larvae may be found in three places according to the species: in the nasal cavities, the walls of the stomach and beneath the skin. The genus *Hypoderma* contains the well-known Warble-flies. It seems that the female lays her eggs on the hairs of cattle. The larvae bore their way through to the walls of the gullet where they remain for a time. Later they are to be found beneath the skin of the back and it is here that they complete their larval development. When full-grown they work their way out through the skin in order to pupate in the ground, the holes they leave thus seriously reducing the value of the hide for commercial purposes.

The Sheep-nostril fly (*Oestrus ovis*) is usually larviparous, and places its maggots in the nostrils of sheep. The growing larvae obstruct the nasal passages and impair the health of the affected animals. Their presence is sometimes responsible for the condition in sheep known as the 'staggers'.

Turning now to the Coleoptera, we find there are numerous examples of species leading a parasitic life. Only one or two cases can be mentioned here. The members of the family Meloidae (Oil- or Blister-beetles) are mostly parasitic. *Apalus*, a meloid genus, passes the larval phase in the nests of solitary bees. Owing to the indirect method by which the parasite reaches its host, *Apalus* lays an enormous number of eggs to offset their very slender chances of survival. Between three and four thousand eggs may be laid in batches in the neighbourhood of the bees' nests. The first stage larvae are active organisms, fitted for a life of movement, showing as yet none of the features of a degenerate parasite. Known as triungulinids, they climb up to the blossoms of plants visited by their nectar- and pollen-seeking hosts.

The Sheep-nostril Fly (*Oestrus ovis*), which lays its eggs in the nostrils of sheep.



When the queen wasp collects wood for making the papery material for its nest it may inadvertently collect the larvae of *Metoecus*, which parasitises the wasp larvae.

Here they wait until an opportunity comes to attach themselves to a bee, which then unwittingly carries off the parasite to its nest. Secure in the cell of the bee, the triungulinid, in response to the requirements of a habitat which offers no scope for free movement, undergoes a gradual change with each successive moult. At first its legs and jaws become smaller and feebler and its body more robust. By the time it is full grown, however, it has become a stout inactive grub with almost functionless limbs.

A beetle with habits similar to those of *Apalus* is the curious looking insect, *Metoecus paradoxus*. Its life history illustrates very vividly the fact that no group of insects, no matter how able its members are to defend themselves, is safe from the attentions of other insect parasites. The host of *Metoecus* is one of the common wasps of Europe, the agressive *Vespula vulgaris*. The beetle lays her eggs in the cracks and crevices of the kind of wood which *Vespula* collects for nest-building. The larvae when first hatched are of the triungulinid type. They attach themselves to a foraging wasp and are transferred to the latter's nest, where each grows to maturity sucking the body juices of a wasp larva.

Diversity is the keynote in the parasitic habits of insects, and is especially true of the Hymenoptera. Instead of laying as many eggs as would equal the potential number of their progeny, the females of certain genera of Encyrtidae, minute but often brilliantly coloured wasps, lay only a few eggs each of which may subdivide to form a great many eggs. This multiplication of an egg into a large number of separate cells within the host leads to the formation of what have been termed embryo chains. In the case of *Litomastix truncatellus*, as many as 3000 adults of which have been bred from a single caterpillar, *Phytometra brassicae*, the embryo chains do not break up into their component parts and hatch into larvae until the host is full grown.

CHAPTER XXIII

ARACHNIDA

(Scorpions, Spiders, Mites and Ticks)

THE members of this class, which includes the King Crabs, Scorpions, Spiders, and the Ticks and Mites, are often mistaken for insects, with which they agree in having a chitinous external skeleton. There the resemblance ends, however, for only in the larval stages of the Mites and Ticks do we find the three pairs of legs typical of insects, nor is the body in any of them divided on the typical insect plan, into three distinct parts. The most distinctive character of the Class is, however, that breathing is effected either by gills, in the few aquatic forms, or through lung-books in the terrestrial forms. Occasionally tracheae may be present, in the latter, but these are always unlike the tracheae of insects.

The class is subdivided as follows:

Sub-class Delobranchiata, aquatic Arachnida, breathing by gills.
Order Xiphosura, the King Crabs.
Sub-class Embolobranchiata, terrestrial Arachnida, breathing by lung-books or tracheae.
Order Scorpionidea, the Scorpions.
Order Araneae, the Spiders.
Order Solifugae, the False Spiders.
Order Chernetidea, the False Scorpions.
Order Opiliones, the Harvesters.
Order Acarina, the Mites and Ticks.

Order Xiphosura

The first order, the Xiphosura, the King or Horseshoe Crabs (see p. 64), have an especial interest. Their fossils are found as far back as the Silurian, which means that these animals have survived unaltered for hundreds of millions of years. To-day they are found in the shallow waters of the Atlantic coast of North America, Japan, the Malay Peninsula and India. They look like living fossils, as indeed they are. The upper surface consists of a large, semicircular, domed shell, followed by a hexagonal abdomen ending in a strong, hinged tail-spine. On the under-surface are five pairs of appendages, used in both walking and feeding, followed by pairs of plate-like gills which not only serve for respiration but assist in swimming. Living on a sandy bottom, into which they habitually burrow, the animals move about in an ungainly manner, assisted by the tail spine. This they dig into the sand and using it as a lever push the body forward.

An Indian Scorpion *(Paelamnaeus)* carrying its young.

The food of King Crabs is marine worms and soft shell-less molluscs.

Order Scorpionidea

Scorpions are, after the King Crabs, the largest Arachnida, the largest measuring some eight inches in length, the smallest a quarter of an inch. The 300 known species are found only in hot countries, and the fact that they never drink makes them suitably adapted to life in the desert. During the day they lie up under stones and in holes, coming out at night to hunt the insects and spiders on which they feed.

The body of a scorpion consists of a head, bearing a pair of formidable chelicerae, or

A bird-eating spider from Brazil and a humming bird on its nest, to show relative sizes.

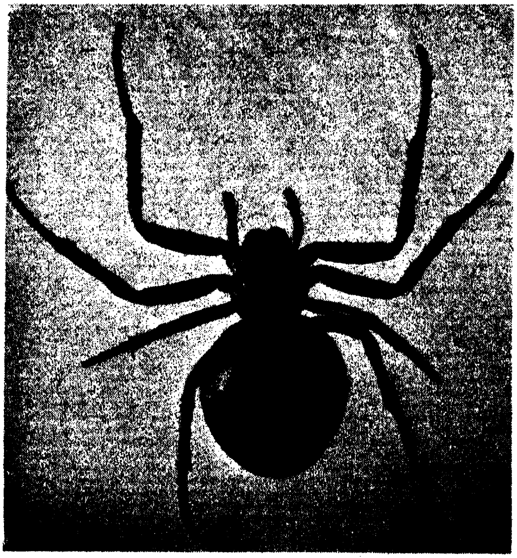
claws, a segmented thorax bearing four pairs of legs on the undersurface, and an abdomen (the so-called tail) of six jointed segments, the last of which ends in a fine, curved point containing the poison duct. Its prey is seized in the chelicerae and torn to pieces. Only if it offers resistance to capture is the sting brought into play. Then the tail is arched forward over the body to stab the victim held in front of the head. Contrary to popular belief, scorpions are not dangerous unless molested. They prefer to avoid attention. To their own kind, however, they are always hostile and it is proverbial that two scorpions will only be found together when mating, or if one is eating the other. As a consequence they lead solitary lives.

The young are born alive and are carried about for the first week on the mother's back.

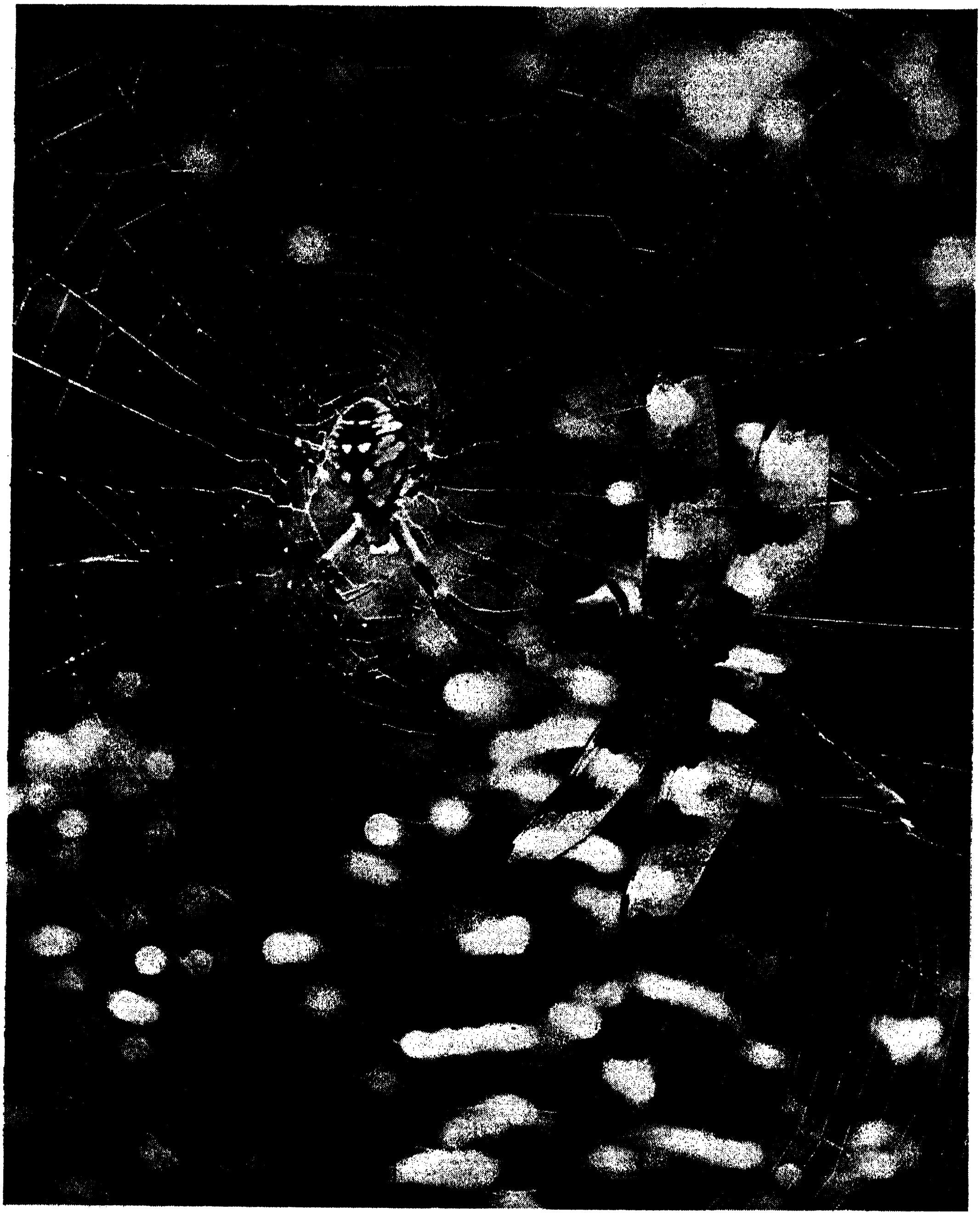
Order Araneae

The 14,000 different species of spiders are remarkably similar in bodily form, but their habits are very diverse, and varied as their ways are they depend for the most part on the use to which the silk threads are put. Although there are a few animals capable of producing silk, for example certain insects, and notably the silkworm of commerce, spiders are inseparably associated in our minds with the spinning of silk.

The spider's body, like that of most other Arachnida, is characteristically divided into a cephalothorax and abdomen. The head and thorax are merged into one, to form the cephalothorax which bears the eyes, usually eight in number, and four pairs of legs. Behind the cephalothorax is the abdomen, with the spinnerets, which exude the silk, at the tip. The only exceptions are certain primitive spiders found in India, the Malay States and Japan, in which the abdomen is segmented, recalling the



This orange-coloured spider shows well the head fused to the thorax and the prominent abdomen, the typical four pairs of legs and the palps in front of the head.



The North American Golden Garden spider, with a dragon-fly caught in its web.

condition believed to have obtained in the ancestors of present-day spiders.

All spiders are carnivorous. At the front of the body are glands secreting a poison which exudes from the fangs. This poison is rapidly lethal to small insects. Certain of the larger

An Orb-spinning Spider *(Argiope lobata)* from the Mediterrean.

spiders are able to kill fish, mice, rats, small birds, even snakes. The bite of most spiders produces, at the most, only a slight irritation in human beings, but a few are known to be dangerous to large quadrupeds. The bad reputation of spiders in general is due largely to the activities of the Black Widow spiders, found mainly in the tropics, the bite of which can bring on acute pain, restlessness, nausea and, in about ten per cent of cases, death.

Spiders are able to consume a large amount of food at one time, and store it in a number of tubes opening out from the intestine. Because of this, they are able to endure long enforced fasts. Or rather, they can live on this reserve for months, or even a year or two, without eating.

The life history of a spider differs from that of the typical insect. There is no metamorphosis but growth is by a series of moults. When first hatched the young one is a small, though imperfect spider. The body is usually transparent, and the alimentary canal is filled with yolk. Often it has no eyes and the mouth is seldom complete. It cannot spin silk. After a time it moults, and at this stage its eyes and spinnerets appear, and it is ready to take its first step into the world, by escaping from the cocoon. At this stage, the first use of silk comes into evidence, in the gossamer with which the young spiders are dispersed.

The typical adult spider tends to shun the light, being most active at night, but the young spider instinctively comes out into the light and shows a strong inclination to climb upwards on the plants, shrubs or fences. At the top it turns its head into the wind, raises the tip of its abdomen and exudes a drop of liquid silk, which the slightest breeze draws out into a long thread. The thread being pulled by the breeze, the young spider releases its grip and sails into the air on its gossamer. Under suitable weather conditions, in spring and autumn, the air can be filled with gossamer threads. This method of dispersal is necessary if the numerous young spiders hatched out in a given cocoon are not to be too crowded together in the competition for food. And it is used by all but the young of the species which burrow in the ground or lurk under stones. The migrations may cover a few yards or up to two hundred miles.

Spiders may be roughly grouped according to their methods of seeking food. There are the hunters and the web-spinners. The former include the wolf-spiders, crab-spiders and the jumping-spiders. The web-spiders may be approximately grouped according to whether they spin a web of loose strands of silk, a sheet web, a flat web connected with a tubular nest or a round web of threads radiating from a common centre and connected by circular loops and spirals.

The wolf-spiders are to be seen running over the earth or through the grass, the females carrying with them a silk cocoon, or egg bag, attached to the spinnerets. Instead of spinning a web and lying in wait for their prey, they go out and hunt it. The young, when first hatched, are carried about on the mother's back until they are able to fend for themselves. The supposed Tarantula of Southern Europe was a wolf-spider which was believed to cause hysteria by its bite, for which the only cure was violent dancing. The name itself is derived from Taranto, in Italy, the dance being called a Tarantella.

Crab-spiders have only a slight resemblance to crabs, but they walk like them. They are short and flat, and the hinder end is wider than the front. The legs extend out to the sides, instead of forwards and backwards. They run sideways and backwards. Their habit is to lurk among fallen leaves, or among the petals of flowers, their colours harmonizing with those of their background, and to dart out on to their unsuspecting victims. Some, like *Misumcria varia*, can change their colour, to yellow if on yellow flowers, to white if on white flowers, the change occupying about 48 hours. In the Malay States and Ceylon there are butterflies which habitually come to rest on bird droppings. The crab-

A Wolf-spider with its cocoon.

A grasshopper caught in the web of a Golden Garden spider is in process of being shrouded with silken threads, against which its struggles are useless.

Psalmopaeus cambridgeii, a Bird-eating Spider from the West Indies, often found in crated bananas.

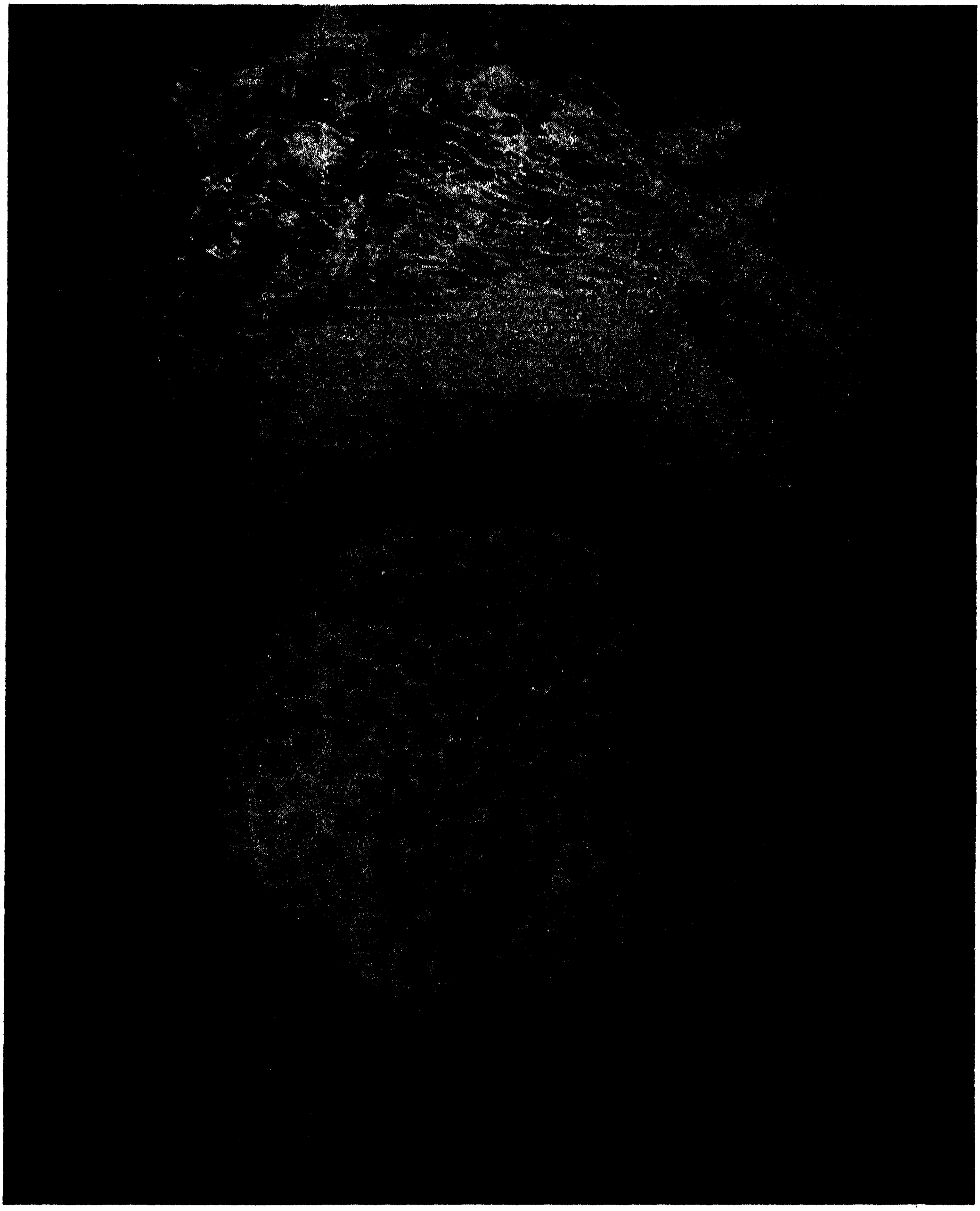
spiders of these areas, belonging to the genus *Phrynarachne*, are black and white in colour. They spin a white, irregular web and then rest in the centre giving a perfect simulation of a bird's dropping, on which their butterfly victims come to rest (cf. p. 361).

In the jumping spiders, which live on the tops of low plants, walls or fences, the body, about a third of an inch in length, is longer than it is broad. They have a large cephalothorax, broad in front. They can move readily forwards, sideways or backwards, and this manœuvrability is combined with an ability to take, for the animal's size, tremendous leaps on to the backs of flies or other insects coming within their territory. They have keen sight and possess a large pair of eyes in front of the head, set close together, and two pairs of smaller eyes wider apart and set further back. Before making their leaps they will stalk their prey in a most skilful and patient manner, flattening the body against the substratum and taking advantage of every irregularity to keep out of sight of the intended victim. As they move about they lay behind them a silk thread, fastened down at intervals, and as they take the final leap, which seldom misses the victim, the thread is played out like a mountaineer's rope. Should they miss their aim and land into space, they can quickly climb back up the silk to the place they have just left. Others hunters include the large bird-eating spiders, commonly transported from their native haunts in crates of bananas. They are usually called Tarantulas although they have nothing to do with the wolf-spiders of Taranto. These are the largest of all spiders, the species native to New Guinea having a body three and a half inches long and a leg span of nearly nine inches. Their habit is to hide under stones and logs, or in the cavities in trees, during the day, coming out at night to hunt. In spite of their size, the bite is little more troublesome than a wasp's sting. Their food consists mainly of insects, though they capture small birds on occasion.

It seems a long way from the drag-line of a jumping spider to the beautifully designed web of the garden spiders, but the view is generally held, and with justification, that the latter is derived from the former. Many webs spun among the leaves of plants and bushes consist of little more than a few strands of silk criss-crossing in an irregular manner: such, for example, as would be formed by a jumping spider moving about in a restricted space but always laying his thread of silk as he moved about. The formation of the sheet webs which are often conspicuous in bushes, or the cobwebs in houses or outbuildings, are merely an exaggerated and intensified form of the simplest webs.

In some of the species that spin irregular sheet webs, the hind legs are fitted each with a comb to control the movement of the silk.

The next step in the evolution comes when the sheet web is continued into a tube in which the the spider rests. Such webs, again, may be seen in the corners of rooms, but the most striking



The side of the egg sac of a Golden Garden spider has been cut away to show the egg cluster inside.

are found in the trapdoor spiders. The European species excavate a tunnel in the earth, having a special row of teeth on the jaws for digging, and line it with a densely woven tube, the outer end of which may be fastened to blades of grass or other herbage. In the true trapdoor spiders of warmer countries the entrance to the burrow is covered with a lid compounded of silk and earth, with a bevelled edge to make it fit closely into the entrance, and hinged with silk. On the underside of the lid are two holes in which the spider fits its claws to pull the lid down.

The beautiful orb-webs represent the highest development, and there is an obvious advantage in the economy of material and effort expended in the spinning of them.

An interesting departure from the normal is found in the water spiders, which spin an inverted bell amid a tangle of waterweeds. This they fill with air. The spider rises to the surface of the water, protrudes its body slightly so that air is trapped among the hairs covering the body, and then swims down to the inverted bell, into which the air is released.

The use of silk is closely associated with reproduction as well as feeding. Indeed, it may be that this was its primary use. At all events, before laying her eggs, the female spider spins a small silken sheet. Then she adds another sheet, or a cushion of silk to receive the eggs, after which fresh layers of silk may be added before the cocoon is finally rounded off. The methods of construction are very varied, as are the final shapes of the cocoons, which range from simple and spherical to elaborate shapes, often ornamented with pieces of leaf or grains of earth as camouflage. Finally, the cocoons are fastened on blades of grass, stems of plants, in the crevices in bark, walls or fences. In some species the mother watches over the cocoon until the young are hatched. As we have already seen, the wolf-spiders carry the cocoons about with them fastened to the spinnerets, and in at least one case, a house-spider, *Pholcus phalangioides*, the cocoon is carried in her jaws. When she eats she may have difficulty in detaching it so closely is the cocoon held.

Spiders are not deliberately cannibals, as is often supposed, but are so voracious that anything living is apt to be attacked. When two spiders meet, therefore, one is likely to be killed and eaten.

There is a widely held view that as soon as a pair

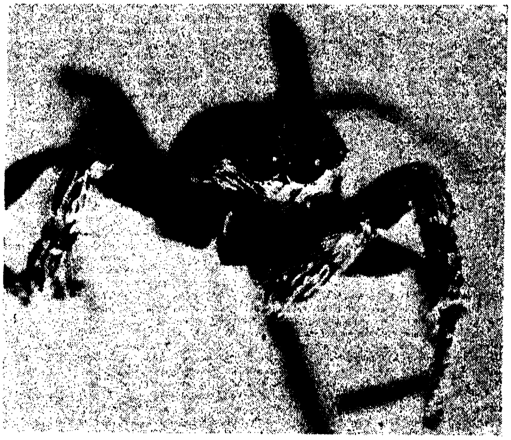
Orb spiders (*Aranea diadema*), showing the relative size of the large female and the smaller male. There is a current belief that the female devours the male as soon as they have mated, but although such action may have been observed, it has yet to be proved that this is the general rule.

of spiders have mated the female eats the male. Doubtless such a thing has happened, since spiders, male or female, are voracious, and are quite prepared to be cannibals. There have been cases where both have lived together in one web after mating has taken place. It has, also, often been said that in order to approach the female the male must proceed with great caution. Observers of this have been misled: they have in fact been witnessing the courtship. Web spiders have poor eyesight. They depend so much on an appreciation of vibrations of the web and its associated strands. The male enters the web of the female and drums on the strands of silk, to which she will reply. In the process, he approaches slowly the spot where the female is crouched. It is this slow approach and the dalliance, associated with all courtship, which can mislead an observer into thinking that the male is scared and afraid to approach his mate-designate.

Spiders which do not spin webs, wolf-, crab-, and jumping-spiders, have keen eyesight. They do not depend on vibrations in the silk threads to warn them of the presence of victims, enemies or mates. Their courtship is therefore concerned with visual display. In jumping-spiders the legs are adorned with tufts of hairs, and these, as well as the coloured markings on the abdomen, are flourished before the eyes of the female. The male may circle the female a hundred times, displaying his charms, before he proceeds to mate with her.

The young spider, as we have seen, does not normally leave the shelter of the cocoon until after the first moult. Then it is capable of fending for itself. As it feeds it grows, becoming too big for the horny cuticle, the exoskeleton, enclosing the body. Pressure from inside causes

A Golden Garden spider hard at work constructing her egg sac. Around and around the sac she travels applying layer after layer of silken web. The egg sac has to be well constructed to protect and provide warmth for the baby spiders during the winter.



Galticus scenicus, one of the Jumping Spiders, appears to have the power of focussing the eyes to produce a definite image.

this to split and come away from the soft body. The most trying part of the moult is getting the legs out, which is done by a series of convulsive jerks of each leg. As many as six hundred may be necessary, so that by the time the moult is finished and the old skin is shed, the spider is exhausted and needs to rest. Then it carefully combs itself all over, presumably to set the hairs in the right direction. For a short while after a moult the spider is paler in colour, becoming darker as the new cuticle hardens.

Spiders have the power of casting a leg if caught by it, and of growing another. The action is voluntary, and the leg is shed at the second joint. The process of regrowth is started as soon as the leg is lost, but the full limb is not restored until the next moult.

The enemies of spiders include birds and other insectivorous animals, wasps, and Ichneumon flies which lay their eggs in the bodies of spiders or in their cocoons. These are sufficiently numerous to be the cause of many measures adopted for concealment. The simplest form is for the spider to hide, either under stones or in crevices, or, like the trap-door spiders, in the ground. Other methods used are protective coloration, the use of decoys, protective resemblance, mimicry, warning colours, shamming dead or seeking invisibility by vibrating the threads of the web.

Order Solifugae

The False Spiders are very like true spiders, but the thorax consists of three segments and the chelicerae are strongly developed, formidable-looking appendages. They are mainly nocturnal, very quick in movement, and hold the first pair of legs well out in front to be used as organs of touch. They feed on insects which they kill with their chelicerae, since they have no poison.

Like the scorpions, their distribution is limited to tropical countries, although some species are found in Southern Europe.

Order Chernetidea

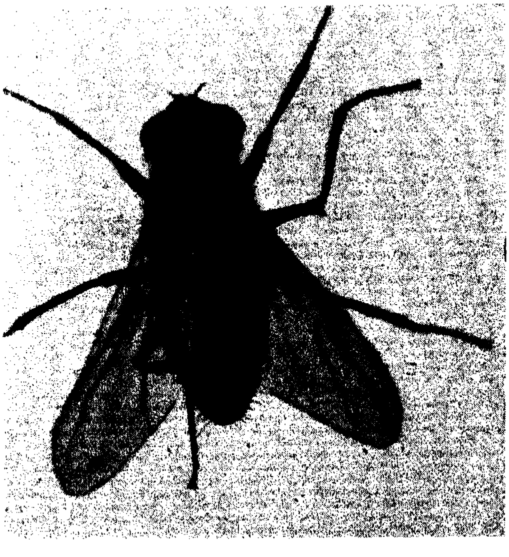
The False Scorpions are of very small size, the largest known is a quarter of an inch long, the

Lycosa narbonenses, a spider living in southern Europe which excavates a burrow in the ground. Here it is seen on the turret of grass which marks the entrance into the burrow.

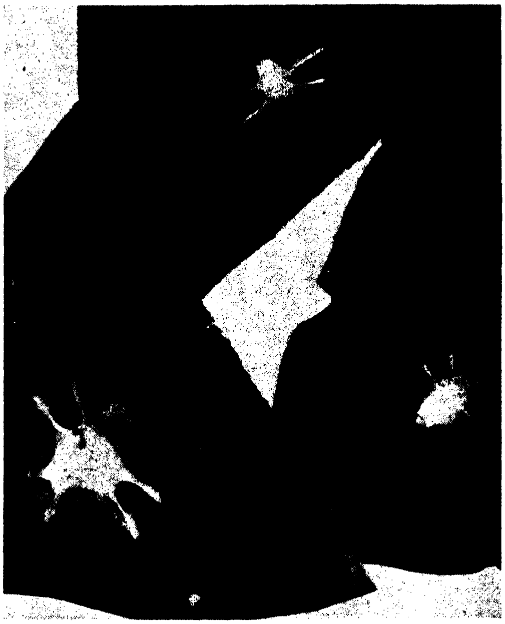
majority less than one tenth of an inch. They feed on mites and insects smaller than themselves, and their habitat is under stones, in moss, under the bark of trees, in manure heaps, in hay and straw and in the crevices in the woodwork of houses and outbuildings.

There is a superficial resemblance only to scorpions. The abdomen is segmented and does not form a tail. There is no sting or poison gland and the chelicerae are small and used for secreting silk, but the palps are large and pincer-like, giving the slight resemblance to scorpions. One of them, the book scorpion, may sometimes be seen in books and papers, especially where they have not been disturbed for some time.

There are two features of the behaviour of these animals especially worthy of comment. Silk nests are made for protection during the moulting period and during the winter. The false scorpion first collects grains of earth or particles of vegetable matter and arranges these in a circle, cementing them on the inside with silk. Successive layers are added in the same manner, recalling the human process of building a wall. The completed nest is only sufficient to contain its builder in comfort. This type of nest is also used as a brood pouch, carried about attached to the parent's body. Some thirty eggs are laid in it. The newly hatched young have a sucking organ by which they appear to feed upon nutritive material from certain glands in the parent's body which is passed into the brood sac.



House-fly with a False Scorpion *(Chernes nodosus)* fastened to the base of its right middle leg. The False Scorpions use this method of transport from one heap of rubbish to another.



Webs of a species of Brazilian spider on the surfaces of leaves. Their resemblance to bird droppings is obvious, and doubtless helps to gain immunity from attack. A number of spiders spin webs of this type, and it is generally recognised that the device is protective.

Order Opiliones

The Harvesters or Harvest Spiders have a compact, rounded body, with no obvious distinction between cephalothorax and abdomen, and four pairs of disproportionately long legs. Their movements are consequently rapid. They feed on small insects, mites, spiders or each other.

Harvesters have no silk glands, so they make no web and spin no cocoon. The eggs are laid under stones or in crevices. There is a pair of eyes, but the sense of touch is the more important, judging by the manner in which the second pair of legs is waved about.

These animals appear to have two main methods of defence against enemies, apart from their speed of movement. Near the eyes are the openings of a pair of glands said to emit an unpleasant odour; but the more obvious defence rests in the ease with which the animal can shed its legs to avoid capture.

Harvesters are found abundantly throughout the world.

Order Acarina

The members of this order, known as mites and ticks, have not received the attention they deserve in view of their impact on human affairs. In the jungle campaigns in the Second World War, however, the importance of mites as carriers of disease could not be overlooked and considerable research was done. One result of this suggests that when we say that there are 20,000 species of Acarina the figure relates to the known species only. The probability is that the total number of species is far in excess of this.

Mites are world wide in distribution. They are found on the ground and in the ground; on plants and in them; on animals, or burrowing in their skin, or even living in the breathing passages. They live in fresh water and in the sea. They are found in all kinds of dead animal and vegetable matter.

The body in both mites and ticks is not conspicuously divided as in other Arachnida. It is rounded, and varies in size according to whether it is gorged with food or not, but in most mites it is barely visible to the naked eye. In front are biting or sucking mouth-parts, and, just behind the head, the four pairs of legs which terminate variously in suckers, claws or bristles according to the habits of the owners.

The life history of these animals, too, differs from that of other Arachnida. The egg hatches to a larva, peculiar in having three pairs of legs instead of the typical four pairs. This later, in most mites, changes to a nymph, when the fourth pair of legs appears.

Not only do these animals indulge in gargantuan feasts, but they are also capable of unusually long fasts. In some cases these fasts have been known to last several years, during which time growth is completely arrested, but proceeds normally again once the fast is broken.

The variety of their habits, as well as the many ways in which they conflict with human interests, is best shown by describing a few of the better-known mites and ticks.

Harvest mite or Chigger. This is the larva of the mite, *Trombicula autumnalis*, which lurks in grass and coarse herbage waiting to get on to the body of a passing animal. It infests rodents particularly, but a great variety of birds and mammals, including man, is subject to their attacks. Having been brushed on to the skin of a passing animal, it bites and releases a drop of fluid, in response to which a tube develops in the skin enabling the mite to feed on the lymph. The result is the formation of localised centres of intense irritation, which last up to a week. Having fed, the mite drops off its host, completing its change to the nymph, and subsequently the adult, in the ground.

Related species of mites in the tropics are known to be the carriers of typhus.

Itch mites. One species burrows in the skin of human beings and, in addition, lays its eggs therein, causing the "seven-year itch". Other species are the cause of scabs on horses. Others, by living in the hair follicles, cause mange in man and other mammals.

Gall mites. These suck the juices of plants and are the cause of the disease of blackcurrant bushes known as "big bud".

Red spider. A pest of gardens and orchards doing much damage to cultivated plants, shrubs and trees. They are vegetable feeders and when present in large numbers whole bushes may be covered with webs under which the females have laid their eggs.

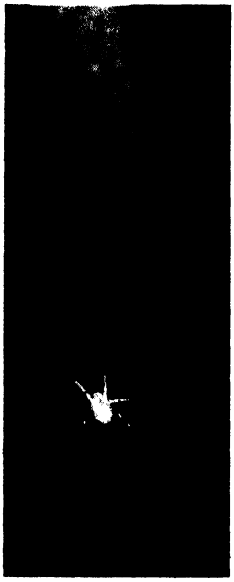
Isle of Wight bee disease. A disease of cultivated bees caused by the presence of mites in their tracheae.

Water mites. These are of two kinds: those living in salt water, which crawl about and burrow in the sand; and those living in fresh water, which have hairy legs by which they are able to swim. They are unusually large—for mites—and brightly coloured. All are carnivorous and some are parasitic.

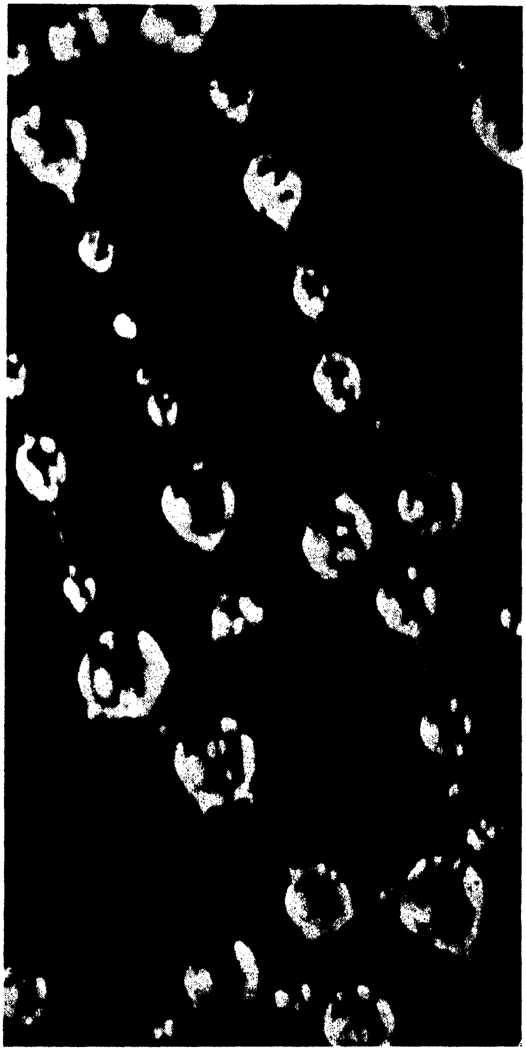
Ticks. The behaviour of ticks is as follows: the larva climbs up a blade of grass or stem of a plant and awaits its opportunity to become attached to the body of a passing animal. Once this is accomplished it plunges its rostrum, a sucking tube leading to the mouth, into the animal's skin and starts to gorge itself with blood. This done, it drops to earth, changes to the nymph and repeats the process. Again it drops to earth, changes to the adult and again climbs up the vegetation to seek the body of a host.

Males and females pair on the body of the host, and this time when the female drops to earth she lays several thousand eggs and the cycle is resumed.

Among the better known diseases caused by ticks are heartwater in sheep, redwater fever in cattle, Texas fever, Rocky Mountain spotted fever. Most of the diseases are caused by lower forms of life, such as Protozoa, viruses and the like transmitted by the tick to its host when biting.



The Harvest Bug, the larva of a mite which infests mammals and birds, and human beings, causing irritating swellings, photographed beside the point of a pin. At this stage the mite has three pairs of legs, but will have four pairs when fully-grown.



Like some rare jewels are the dewdrops on a spider's web, magnified many times their normal size.

The Jumping Spider

A study in behaviour

The Zebra spider is not content to make a snare and squat waiting for his prey. He is a hunter in every sense of the word, a brilliant exponent of the art of stalking. The fact that the body is striped, white against a dark background, is the only justification for comparing him with a zebra. In his habits he more nearly resembles a tiger. To see something of his prowess, it is necessary only to search, with a little patience, the cracks and crevices of a wall on a fine day, looking for a small spider with striped body no more than a quarter of an inch long; then to wait quietly for a fly to settle on the wall.

In his hunting, the Zebra spider depends largely on speed of movement and skill in stalking, in both of which he is aided by an extraordinary power of vision. Two large eyes in front and one on each side of the head, and two pairs of smaller eyes on the top of the head, make up a most formidable battery, which enables him to look in all directions at once. The full significance of this will be readily appreciated. The hunter needs not only to see his prey and be able to catch its every movement, but must be on the look-out for every bit of cover. And further, lest the hunter becomes in turn the hunted, a careful watch for his own safety must be maintained.

A fly settling on the wall a few inches away has caught our spider's attention. With his eyes riveted on it, he slowly lowers the head and depresses the body, and begins to make his way slowly towards it, moving one leg at a time. The whole action is absurdly cat-like. But a fly, too, has good sight, and is startled at the slightest movement, and to creep across the intervening space at a sufficiently slow speed to allay suspicion would take too long, the chances being that the fly would move away before the spider got near enough for a spring. Caution is, therefore, not enough; speed must also be used. But to move rapidly across the bare face of the brick would be to run the risk of startling the fly. With stealthy movement the spider reaches a slight crack in the brickwork and cautiously drops into it. In a moment, the whole movement changes. He springs to life and runs rapidly along the crack, stopping at intervals to peer over the edge, to make sure that the fly is still there. The crack ends; the spider must crawl once again over the exposed surface of the brick. He is getting near the fly and is preparing to spring, but before doing so he throws out a thread of silk and fastens it to the surface of the brick. But the fly has seen him. As if conscious of approaching danger, or perhaps only to change to a better position, it takes wing.

The spider is used to disappointment—the hunter does not always get his quarry—but he knows from experience that when a fly rises it may go right away or it may take off for a brief spell and come to rest again in much the same spot. So he follows it with his eyes to see what it is going to do. The fly lands again on the wall some inches from the spot it has recently left. The spider waits until it has folded its wings and shows every sign of remaining quiet for a while, then begins again to stalk it. Again the stealthy movement, taking advantage of each prominence and irregularity in the surface of the wall; again the short, sharp dash along each convenient crevice until within leaping distance. This time the silken thread has been played out continuously as the spider moved, and fastened down at intervals. This is the life-line. Shortly the spider will spring, and the spring may land him anywhere. He may miscalculate the distance, miss his footing and fall from the wall; or the fly may move and throw his calculations out. In any case, he is prepared; the life-line will hold him in mid-air and provide him with the means of climbing back to the wall.

Arrived at a convenient point, the spider prepares to leap, hunches his legs under him and springs into the air. The fly, suddenly aware of danger, makes a movement to unfold its wings. But, too late! With a leap, truly prodigious for so small an animal, the spider has landed on the fly's back and buried his fangs deep in its body.

SYSTEMATIC INDEX

Since certain animals are mentioned in both Volume I and Volume II, the reader should consult the indexes in both volumes for full information

Abalone, 204
abildgaardi, Sparisoma, 133
Acanthocephala, 163, 172
acanthocera, Pachyrhamna, 263
Acarina, 362–363
Acorn barnacles, 218
aculeata, Ophiopholis, 148
Adalia bipunctata, 307
Adephaga, 303–306
aquaticus, Asellus, 223
Aedes, 339
A. egypti, 344
Aepyornis, 71
Aeshna dragon-fly, 272
Aesop prawn, 225
African ant, 332
African elephant, 6
African wasps, 330
Alaskan brown bear, 98
albida, Ophiura, 247
Alcyonarian, 160, 162
Alcyonium digitatum, 155
Alder-flies, 258, 287
Ambrosia beetles, 311
American black slug, 198
American blight, 250
American bot-fly, 274
American buffalo, 67
American cockroach, 260
American oyster, 39, 252
americana, Belostoma, 278
americana, Periplaneta, 259
Ammonites, 60
Ammophila, 326
Amoeba, 1, 10, 27, 28–29, 30, 32, 34, 35, 37, 41, 44, 46, 47, 48, 77, 135, 137, 138
Amoeba proteus, 1, 10, 27, 28–29, 30, 32, 34, 35, 37, 41, 44, 46, 47, 48, 77, 135, 137, 138
Amphilectus challengeri, 120
Amphineura, 197, 198–199
Amphipoda, 223
Amphipolis squamata, 188
Amphydasis betularia, 247
Ananea diadema, 359
Anasa tristis, 276
Anaspidacea, 221–222
Anaspides tasmaniae, 221, 222
Anastostoma australiae, 264
Ancistromesus mexicanus, 204
Ancylostoma duodenale, 173
Anergates atratulus, 336
Angel-fish, 133, 134
Angler-fish, 119
Anisoptera, 316
Anisotremus virginicus, 133
Annelid worm, 218, 254
Annelida, 147, 163, 164–166
Anobium punctatum, 308
Anodonta cygnaea, 203
Anomura, 226–227
Anopheles, 339
Anoplura, 258, 269, 347
Anthia, 304
Anthozoa, 152, 155–158
Ant-lions, 287
Ants, 118, 254, 258, 306, 317, 319, 320–336
Apalus, 349
Apanteles glomeratus, 348
Aphides, 248–252, 281, 348
Aphidius, 319, 348
Aphrodite, 166
Apis, 332, 334, 336
A. dorsata, 335
A. mellifera, 333, 334
apodus, Lutianus, 131
apollyon, Paractopus, 214
Apple snails, 204
aptera, Tricondyla, 304
Apterygota, 258
Arachnida, 351–364
Aranea diadema, 359
Araneae, 352–360
araunus, Megalotractus, 205
arborifer, Linophryne, 119
Arcella, 138
Archaeopteryx, 60
Archaster typicus, 188
Architeuthis princeps, 210, 214
arctos, Ursus, 2
arcuarius, Kuphus, 211
Argiope lopata, 354
Argonauta tuberculosa, 212
Argulus, 219
argus, Cypraea, 211
Arion ater, 207
Armadillium vulgare, 246

Armadillo, 63, 199, 246, 277
armatum, Cardesoma, 229
Army worm moth, 348
Arrow-worms, 171, 172
Arthropoda, 215–229
Ascalaphus-flies, 287
Ascaris, 171
ascensionis, Holocentrus, 130
Asellus aquaticus, 223
Aspergillum, 211
aspergillum, Euplectella, 144
aspersa, Helix, 171, 203, 213
Aspidiotus perniciosus, 281
Assassin bugs, 277
Asterias mülleri, 39
A. rubens, 39, 176, 252
Asteroidea, 177–179
Astrochlamys brunneus, 188
Astropyga radiata, 183
ater, Arion, 207
atratulus, Anergates, 336
Attacus cynthia, 92
aurantium, Tethya, 147
Aurelia aurita, 122
aureus, Pomacanthus, 122
auricularia, Forficula, 260
aurita, Aurelia, 122
australiae, Anastostoma, 264
Australian ladybird, 307
Australian lungfish, 16
Australian marsupial wolf, 69
Automobile bugs, 308
autumnalis, Trombicula, 362

Back swimmers, 278
Badger, 97
Balantidium coli, 142
bancrofti, Wuchereria, 344
Barbers, 277
Bark beetles, 310
Barnacles, 126, 178, 218–219, 221
Barracuda, 132
barracuda, Sphyraena, 132
Basommatophora, 207
Bats, 14, 97
Bean ladybird, 307
Bears, 79, 98
Bed bug, 277, 347
Bee louse, 17
Bees, 142, 258, 272, 317, 320–336
betularia, Amphydasis, 247
Beetles, 256, 258, 283, 285, 300, 303–311, 312, 313, 314, 337
Bell animalcule, 142
Belonogaster, 330
Belostoma americana, 278
Benacus griseus, 278
Betaurus stellaris, 82
Bladder worms, 173
blanca, Leucosolenia, 143
Blissus leucopterus, 276
Blister beetles, 308–309, 349
Blood flukes, 173, 174
Blow-flies, 255, 338, 340
Blue whale, 252
Bluebottles, 340, 341
Blatta orientalis, 259
Blattella germanica, 259
boas, Oryctes, 309
Bombardier beetles, 304
Bombus, 329, 331, 332, 333, 336
Bonellia, 166
Book-lice, 258, 269
Bopyroides hippolytes, 223
Borus oblongus, 201, 216
Bot-flies, 341, 344, 349
Brachinus, 304
betulae, Rhynchites, 310
bicolor, Stenobothrus, 262
Big bed-bug, 277
Biorhiza pallida, 318
Bipalium kewense, 168, 169
bipes, Nebalia, 221
bipunctata, Adalia, 307
bipunctata, Coccinella, 251
Birch-leaf-rolling weevil, 310
Bird lice, 347
Bird-eating spider, 352, 356
Birds, 282
Birgus latro, 227
Bison, 67, 282
Biting lice, 269, 347
Bittern, 82
Bivalves, 198, 208–209
Black angel-fish, 122
Black panther, 109
Black slugs, 200, 201
Black widow spiders, 354
Blackbeetle, 259
Brachinus crepitans, 304
B. displosor, 304
B. fumans, 304
Brachiopoda, 191–194
Brachygenus chrysargyreus, 96
Brachyura, 227–228
Branchiopoda, 218
brassicae, Phytometra, 350
Brauta coeca, 17
Brazilian land snails, 201, 216
Bridge worms, 163, 166
Brine shrimps, 218
Bristle-jaws, 172
Bristle-mouthed worms, 163, 172
Bristle-tails, 258
Bristle-worm, 121, 147, 163, 164–166
Brittle-stars, 147, 148, 175, 179–180, 184, 186, 247
Brown bear, 2
brullei, Tanusia, 263
brunneus, Astrochlamys, 188
Bubo bubo, 106

Buccinum, 213
Buffalo, 282
Buffalo moth, 306
Bugs, 254, 258, 275–281, 283, 299, 312, 314, 347
Bulldog ants, 322
Bullfrog, 99
Bumble-bee, 329, 331, 332, 333
Bursaria, 195
B. paramecium, 232
Burying beetles, 300, 303, 306, 309
buski, *Fasciolopsis*, 174
Bustards, 110
Butterflies, 86, 113, 248, 257, 258, 283, 288–298, 301, 302, 337, 348, 355

Cabbage-bug, 276
Cactoblastis cactorum, 285
cactorum, *Cactoblastis*, 285
Caddis-fly, 258, 288, 312, 315
Caddis-worm, 288, 314, 315
caespitum, *Tetramorium*, 336
Cake-urchins, 180–181
Calandra oryzae, 307
Californian sea-lion, 16
californianus, *Zalophus*, 16
Calliactis parasitica, 233
Caligo, 298
Calling crabs, 228
Callistochiton magdalenensis, 199
Callithaera menander, 296
Calosoma sycophanta, 282
cambridgeii, *Psalmopaeus*, 356
Camel, 41, 236
Camponotus, 319
Cancer pagurus, 252
Canis dingo, 4
canus, *Larus*, 53
Cape penguin, 52, 80
Carabus violaceus, 304
Caranx ruber, 133
Carcinus maenas, 39
C. pagurus, 39
Cardesoma armatum, 229
cardinalis, *Vedalia*, 307
Cardum edule, 208
Carebara, 332
Caribou, 49
Carnivorous water-beetles, 304–305
Carpet beetle, 306
Carpet bug, 306
Carteria lacca, 281
Caterpillars, 288–298, 299
Catfish, 237
caudata, *Nereis*, 165
caudatum, *Paramoecium*, 140
Cecropia moth, 87, 290, 291, 292, 293, 294, 297
cellulosae, *Cysticercus*, 173
Centipedes, 244–246
Centrechinus setosus, 180
Cephalodiscus, 193
C. longstaffi, 17
Cephalopoda, 198, 209–212
Ceratocoris horni, 276
Cerebratulus lacteus, 39
cervus, *Lucanus*, 309
Cestoda, 170
Chaetognatha, 163, 172
Chaetopterus variopedatus, 39
challengeri, *Amphilectus*, 120
chalumnea, *Latimeria*, 128
Chameleons, 271
Cheetahs, 110
Chernes nodosus, 361
Chernetidea, 360–361
Chigger, 362
Chilopoda, 245, 246
Chinch bug, 276
Chiton, 197, 198–199, 203
chrysargyreus, *Brachygenys*, 96
chrysopae, *Perilampus*, 318
Chrysops, 344
chrysurus, *Ocyurus*, 131
Cicada, 275, 278–281, 331, 343
Cicada wasp, 331
Cidarid sea-urchin, 183, 184
ciliaris, *Luida*, 39, 252
ciliata, *Polydora*, 39
Cimex, 347
C. lectularius, 277
Cinnabar moth, 300
Circular crab, 239
Cirripedia, 218–219
Civet cats, 110
Clams, 180, 203, 208, 209, 232
Clava squamata, 150
clavata, *Raia*, 167
Claviger testaceus, 306
Clavularia inflata, 162
Clearwing saturnid butterfly, 296
Click beetles, 308
Clonorchis sinensis, 174
Clupea, 39
clytia, *Papilio*, var. *dissimilis*, 248
clytia, *Papilio*, var. *panope*, 248
Coat-of-mail shells, 197, 198–199
Coccinella bipunctata, 251
C. septempunctata, 307
coccus, *Dactylopius*, 281
Cockchafer, 304, 309–310
Cockle, 207, 208
Cockroaches, 258, 259–264, 265, 266
Coconut crab, 227
Coconut moth, 284
Cod, 39, 239
Codling moth, 286
coeca, *Brauta*, 17
Coelenterata, 149–158
Coenobita, 227
Coleoptera, 258, 349–350
coli, *Balantidium*, 142

coli, Endamoeba, 138
Collembola, 258, 312
Colorado beetle, 283, 310
Comb-bearers, 152, 158
Comb-jellies, 152, 158
Common earwig, 266
Common house-fly, 342
Common limpet, 203
Common octopus, 209
Common shrimp, 225
Compsilura concinnata, 282–283
compressa, Grantia, 44
concinnata, Compsilura, 282–283
Cone shells, 205
Conger, 239
convergens, Hippodamia, 286
Convoluta roscoffensis, 168, 232
Copepoda, 218
Coral, 26, 38, 130–132, 133, 152, 155–158, 159–162, 189–191, 202, 230, 231, 232
cordatum, Echinocardium, 126, 185
Corixa, 278
Corixidae, 316
Cormorants, 102
cornuta, Corydalis, 287
corrupta, Epelachna, 307
Corydalis cornuta, 287
Cosmopolitan rice weevil, 307
Cotton stainers, 276, 277
Cotton-boll weevil, 310
Cottony cushion, 281
Cottony cushion scale, 284
Cougar, 40
Cow, 37
Cowrie, 205, 211
Crabs, 39, 121, 126, 179, 192, 210, 218, 220, 223, 238–239, 240, 247, 252
Crab spiders, 355, 359
crabo, Vespa, 332
cracherodii, Haliotis, 204
Crane-fly, 338
Crangon crangon, 39
C. vulgaris, 225
Craspidacusta, 155
Craspidaster hesperis, 203
crassidens, Pseudorca, 72
Crawler, 287
Crayfish, 103, 220–221, 224–249
Crepidula fornicata, 205
crepitans, Brachinus, 304
Crickets, 256, 258, 259–264
Crinoids, 116
crispum, Elphidium (Polystomella), 135, 136
Cristatella, 191
Crocodile bird, 236
Crustacea, 215–229
Cryptochiton stelleri, 198
Ctenophora, 152, 158
Cuckoo-bees, 329
Cuckoo-spit, 281
Culex, 338, 339
C. fatigans, 344
C. pipiens, 339
Cumacea, 222
Cuttlefish, 210, 211
Cyclops, 23, 218
cygnaea, Anodonta, 203
cynocephalus, Thylacinus, 5
cynthia, Attacus, 92
Cynthia moth, 92
Cypraea argus, 211
Cysticercus cellulosae, 173

Dactylopius, 281
D. coccus, 281
Dacus tryoni, 339
Daddy long-legs, 277, 337
Danaus plexippus, 296
Daphnia, 217
"Dead-leaf" butterflies, 299
Dead man's fingers, 155
Death watch beetle, 308
Decapoda, 244–249
decemlineata, Leptinotarsa, 283
Deer, 37, 49
Delias descombesi, 248
Demoiselle dragon-fly, 272
Dentalium eutalia, 211
depurator, Portunus, 228
Dermatobia hominis, 344
descombesi, Delias, 248
Devils' coach horse, 306
"Diabolical spectre", 300
diabolicum, Idolium, 300
Diadem spider, 83
Diadema, 187
diadema, Aranea, 359
Difflugia, 138
Digger wasps, 322, 326
digitatum, Alcyonium, 155
Dingo, 5
dingo, Canis, 4
Dinobryon, 139
Dinosaur, 60, 128
Diphyes, 153
Diplodocus, 60, 61
Diplopoda, 246
Diptera, 258, 337–347, 348–349
displosor, Brachinus, 304
divinatorius, Troctes, 269
Dobson-fly, 287
Dodo, 68, 69
Dogs, 41, 169
Dogfish, 65, 118
Domestic fowl, 45, 71
domestica, Musca, 339–340
domesticus, Felis, 18
domesticus, Gryllus, 264
Dorsata, Apis, 335
Doves, 105

Dragonfly, 117, 258, 270–272, 273, 274, 287, 312, 315, 345, 353
Driver ant, 322
Drosophila, 339
Duck-billed platypus, 78
dumerilii, *Nereis*, 165
Dung beetles, 303, 309
duodenale, *Ancylostoma*, 173
Dynastes hercules, 309
Dysdereus, 276
Dytiscus, 313, 314
D. marginalis, 314

Eagle owl, 106
Ear-shells, 204
Earthworm, 121, 147, 163, 164–166, 168, 199, 207, 237
Earwigs, 258, 259–264
Ebalia tuberosa, 240
Echinocardium cordatum, 126, 185
Echinodermata, 176–182
Echinoidea, 180–181
Echiurus, 166
edule, *Cardium*, 208
edulis, *Mytilus*, 39, 127, 252
edulis, *Ostrea*, 39
Eels, 85, 120
egypti, *Aedes*, 344
Eland, 47–48
Elephant, 63
Elephant tusk shell, 211
Electric light bugs, 278
Elphidium (Polystomella) crispum, 135, 136
Embia major, 268
Embioptera, 258, 268
Endamoeba coli, 138
E. histolitica, 138
Endopterygota, 258
entalis, *Dentalium*, 211
Ephemera vulgata, 270
Ephemeroptera, 258, 269–270
Ephydra hians, 342
Epilachna corrupta, 307
equi, *Gastrophilus*, 341, 347
Eristalinae, 313
Eucarida, 223
Eudorina, 46
Euglena, 38, 46, 138, 139
Euparyphium ilocanum, 174
Euphausia frigida, 128, 129
E. longirostris, 128
E. vallentini, 128, 129
Euphausiacea, 224
Euphausians, 128
Euplectella aspergillum, 144
European corn-borers, 284
European oyster, 39
Eurycanthus horrida, 254
Eurydema oleracea, 276
Eurygaster maurus, 276
Exopterygota, 258, 259–264
Eye-worm, 344

Fairy shrimps, 218
Falcon, 114
False killer, 72
False scorpions, 360–361
False spiders, 360
fascifer, *Pachyrhamna*, 263
Fasciola, 169
F. hepatica, 169, 174
Fasciolaria gigantea, 205
Fasciolopsis buski, 174
fatigans, *Culex*, 344
Fawn, 31
Feather-stars, 166, 175, 182, 185
felina, *Tealia*, 33
Felis domesticus, 18
Fer-de-lance, 69
Fiber zibethicus, 2
Fiddler crabs, 228
Fierasfer, 236
Finches, 74
Fire bugs, 276
Fire-flies, 43, 308
Fish, 39
Fish-lice, 218, 219
Fissurella graeca, 211
flabellicornis, *Tetralobus*, 308
Flagellates, 138
Flatta, 301
Flatworms, 147, 158, 163, 168–170, 172, 196, 232
flavus, *Lasius*, 320
Flea-beetles, 24
Fleas, 258, 346–347
Flesus, 39
Flies, 258, 272, 283, 284, 312, 314–315
Flies, two-winged, 337–347
Flounder, 39
Flour moth, 286
Flower-wasps, 322
Flukes, 169–170, 174
Flustra foliacea, 189, 190
Fluted crab, 239
Fluted scale, 281, 284
fluviatilis, *Ephydatia*, 146
Flying bed-bug, 277
Folcus phalangoides, 86
foliacea, *Flustra*, 189, 190
foliacea, *Lepralia*, 191
Foraminifera, 136, 137
forficatus, *Lithobius*, 245
Formica fusca, 336
F. sanguinea, 336
fornicata, *Crepidula*, 205
Forficula auricularia, 260
forsteri, *Neoceratodus*, 16
Fox, 96, 282
fragilis, *Ophiothrix*, 187
francisarus, *Strongylocentrus*, 183

Freshwater mussels, 117
Freshwater shrimps, 221, 222, 223
frigida, Euphausia, 128, 129
Frogs, 142, 271
Frog-hoppers, 280, 281
Fruit-flies, 339
Furniture beetle, 303, 308
fusca, Formica, 336
fusca, Hydra, 232
fumans, Brachinus, 304
furcata, Nereis, 162, 233

Gadus, 39
Galeus, 65
Gall-flies, 258, 318–320
Gall-mites, 362
Galticus scenicus, 360
Garden snail, 121, 213
Garden spider, 353, 355, 356, 357, 359
Gastrophilus equi, 341, 347
Gastropoda, 197, 199–208
Gastrotricha, 163, 168
Gemmules, 194
Geniculatus, Leptocorisa, 276
Gephyrea, 163, 166
German cockroach, 259
germanica, Blattella, 259
Gerridae, 312
Gerris thoracia, 312
Ghost-like catfish, 237
Giant centipede, 245
Giant clam, 208, 232, 233
Giant fish-killer, 278
Giant sea-anemone, 161
Giant spider crab, 227–228
Giant water-bug, 14
Giant wood-wasp, 319
gigantea, Fasciolaria, 205
gigantea, Tipula, 337
gigas, Scolopendra, 245
gigas, Sirex, 319
Gipsy moth, 304
gleuca, Notonecta, 314
Glaudina, 207
Globigerina, 124
glomeratus, Apanteles, 348
Glow-worm, 43, 308
Glyptodon, 63
Gnats, 258, 316
Goats, 68
Golden garden spider, 353, 355, 357, 359
Goldfish, 248
Goliath beetle, 303
Goniopora, 161
Goose barnacle, 220, 221
Gorgon-head starfish, 179
graeca, Fissurella, 211
grandis, Plagiobrissus, 184, 185
Grantia compressa, 44
Grasshoppers, 7, 255, 258, 259–264, 299, 355
Great auk, 68
Great barracuda, 132
Great carnivorous water-beetle, 305
Great water-beetle, 308, 313, 314
Green woodpecker, 118
Greenbottles, 340
Greenfly, 248–252, 319
Grey squirrel, 108
griseus, Benaeus, 278
Ground-beetles, 303–306
Ground-hog, 90
Grunts, 96, 133
Gryllotalpa, 264
Gryllus domesticus, 264
Gulls, 53, 96, 239
Gum-tree bug, 276
Gymnopleurus, 309
Gipsy moth, 282–283, 284
Gyrinidae, 312
Gyrinus, 315

Haemelon parra, 133
H. sciurus, 131, 133
Hairy flower-wasps, 323
Haliotis cracherodii, 204
H. tuberculata, 204
Halobates, 254, 277
Hare, 114
Harlequin bug, 276
Harlequin fly, 315
Harvest bug, 363
Harvest mite, 362
Harvest spider, 361
Harvester ant, 322, 336
Harvesters, 361
Hawk moths, 295
Heart-urchin, 126, 184, 185
hecuba, Morpho, 288
Hedgehog, 54, 112
Helix aspersa, 171, 203, 213
Hellgramite, 287
Hemiptera, 258, 275–281
Henricia sanguinolenta, 39, 187
hepatica, Fasciola, 169, 174
Hercules beetle, 309
hercules, Dynastes, 309
Hermit crabs, 224, 226–227, 234–235
Heron, 82
Herring, 39, 102, 118, 218
Hesperis Craspidaster, 203
Hessian fly, 338
Heterodontus, 65
Heteroptera, 275–278
hexactis, Ophionotus, 187, 188
hians, Ephydra, 342
Hippodamia convergens, 286
Hippolyte varians, 225
hippolytes, Bopyroides, 223
Hippopotamus, 101
histolitica, Endamoeba, 138

Holocentrus ascensionis, 130
Holothuroidea, 181–182
Homarus vulgaris, 39, 226
hominus, Dermatobia, 344
Homo sapiens, 18
Homoptera, 278–281
Honey-bee, 272, 332, 333
Honey-pot ant, 322, 336
hookeri, Limnaea, 207
Hookworm, 171
Hoplocarida, 228–229
Horn-tails, 317
Hornet, 332
horni, Ceratocoris, 276
horrida, Eurycanthus, 254
Horse, 41
Horse-flies, 338, 342
Horse-hair worm, 171
Horseshoe crab, 64, 65, 351
hortideorum, Myrmecocystus, 336
Hottentot bug, 276
House cricket, 264
House-fly, 272, 341, 361
House-spider, 358
Hover-fly, 252, 313, 342
Human bot-fly, 344
Humming bird, 71, 352
Humming-bird hawk-moth, 272
Hunting spiders, 118
hyalinus, Perilampus, 319
Hyas, 239
Hydra, 152, 195, 196
H. fusca, 232
H. viridis, 232
Hydractinia, 233
Hydroids, 51
Hydrous piceus, 314
Hydrozoa, 152–153
Hymenoptera, 258, 317–336, 348
Hypoderma, 349

Icerya purchasi, 284
Ichneumon-flies, 251, 258, 318–320, 346
Ichthyosaur, 57
Idolium diabolicum, 300
Idotea, 223
ilocanum, Euparyphium, 174
imperator, Pandinus, 238
Imperial scorpion, 238
Indian leaf butterfly, 299
indicus, Lethocerus, 278
inflata, Clavularia, 162
Insecta, 247–350
irridescens, Levuana, 284
Isle of Wight bee disease, 362
Isopoda, 222–223
Isoptera, 258, 264–268
Itch mites, 362

Jackals, 110
Japanese beetle, 284, 285, 286, 305
japonica, Popillia, 285
Jellyfish, 55, 121, 122, 150, 151, 152, 153–155, 195, 196
Julus terrestris, 245, 246
Jumping plant-lice, 281
Jumping spiders, 88, 356, 359, 360, 363–364
June beetles, 310
June bug, 310

Kallima, 299
Katydid, 263
kewense, Bipalium, 168, 169
Keyhole limpet, 204, 211
King crab, 64, 65, 192
King cricket, 264
Kissing bug, 277
Koala, 76
Kuphus arcuarius, 211

Labia minor, 260
lacca, Carterica, 281
Lace corals, 189–191
Lacewing, 251, 253, 258, 287, 312, 318
Lachnostera, 310
lacteus, Cerebratulus, 39
Lady beetle, 284, 286
Ladybirds, 250, 251, 307–308
Lamellibranchia, 198, 208–209
Lamellicorn beetle, 309–310
Lamp shells, 191–194
Land bugs, 275–277
Land crab, 228, 229
Langouste, 226
Lapland bunting, 118
Large white butterfly, 348
Larus canus, 53
Lasius flavus, 320
lata, Panesthia, 260
Latimeria, 66, 116
L. chalumnea, 128
latro, Birgus, 227
Leaf insects, 262
Leaf-footed bug, 277
Leaf-hoppers, 275, 278–281
Leaf-spinning ant, 254
Leaf-suckers, 275, 281
lectularius, Cimex, 277
Leeches, 163, 164–166, 167, 236
Legionary ant, 322
Leishmannia, 140
Leopard, 19, 110
Lepeta, 204
Lepidoptera, 258, 288–298
Lepidosaphes, 281
Lepisma saccharina, 14
Lepralia foliacea, 191
Leptinotarsa decemlineata, 283
Leptocorisa geniculatus, 276
Lesser earwig, 260

Lethocerus indicus, 278
Leucosolenia blanca, 143
Levuana iridescens, 284
lewisi, *Trypanosoma*, 140
Lice, 218, 219, 258, 269, 347
Litomastix truncatellus, 350
Limnaea, 169
L. hookeri, 207
L. stagnalis, 207
Limpets, 203, 204–205, 252
Limulus polyphemus, 64
Linckia loevigata, 181
Ling, 39
Lingula, 64, 65, 192, 193
Lingulella, 65
Linophryne arborifer, 119
Lion, 8, 32, 35, 110
listronica, *Murgantia*, 276
Lithobius forficatus, 245
littorea, *Littorina*, 39, 94, 204
Littorina littorea, 39, 94, 204
L. obtusata, 94
L. saxatilis, 94
Liver fluke, 169, 173, 174
Lizards, 148
Loa loa, 344
lobata, *Argiope*, 354
Lobsters, 39, 114, 126, 218, 220–221, 223, 224–249, 258, 259–264, 348–349
Locusts, 348–349
loevigata, *Linckia*, 181
Long-horned grasshopper, 263, 264
Longicorn beetle, 310
longirostris, *Euphausia*, 128
longirostris, *Macropodia*, 240
longstaffi, *Cephalodiscus*, 17
Lophyrus, 52
Lucanus cervus, 309
Luidia ciliaris, 39, 252
L. sarsi, 187
L. unilifera, 148
Lung fluke, 174
Lutianus apodus, 131
Lutra vulgaris, 121
luzonica, *Pila*, 174
Lycosa narbonensis, 360
Lygocerus, 348
Lyre-bird, 50

maenas, *Carcinus*, 39
machaon, *Papilio*, 289
Mackerel, 218
Macropodia longirostris, 240
maculata, *Synapta*, 181
magdalenensis, *Callistochiton*, 199
Magilus, 202
Maia squinado, 239
major, *Embia*, 268
Malacostraca, 220–221
Mallophaga, 347
Mango fly, 344
Mantichora, 304
manticida, *Riela*, 319–320
Mantis shrimp, 221, 228–229
marginalis, *Dytiscus*, 314
Marine slugs, 207
Marsupial wolf, 5
martinicus, *Mulliodichthys*, 131
Mason-bees, 328–329
Mason-wasps, 323, 324
Mastigophora, 138
materna, *Ophiodaphne*, 188
maurus, *Eurygaster*, 276
May beetle, 310
May bug, 309–310
May-fly, 258, 269–270, 312
Medusa, 153
Megalotractus araunus, 205
Mealy-bugs, 281
Melia tessellata, 228
Melicerta, 167
mellifera, *Apis*, 333, 334
Mellita quinquisperforata, 185
Meloidae, 349
Melolontha vulgaris, 310
Melusinidae, 316
Membranipora pilosa, 191
menander, *Callithaera*, 296
Metoecus, 349
M. paradoxus, 349–350
Mexican scarab beetle, 309
mexicanus, *Ancistromesus*, 204
Mice, 282
Midges, 258, 314, 338
Migratory locusts, 348–349
Millepede, 81, 244–246
Milkweed butterfly, 296
Miner's hookworm, 173
minor, *Labia*, 260
Minyas, 155
mirabilis, *Pelagohydra*, 72
Misumeria varia, 355
Mites, 362–363
Mitten crab, 174
Moas, 67–68
Mole, 42
Mole crab, 227
Mole cricket, 256, 263, 264
Mollusca, 197–214
Molva, 39
Monarch butterfly, 283, 296, 298
Mongoose, 69
Monocystis, 195
Mononyx, 299
morio, *Epinephelus*, 132
Morpho hecuba, 288
Mosquitoes, 143, 338–339, 344
Moss animals, 189–191
Moths, 85, 91, 247, 256, 258, 272, 282–283, 284, 286, 288–298, 302, 304, 348

Mountain shrimp, 220, 221, 222
Mouse-eared bat, 97
Mud-daubers, 324
mülleri, Asterias, 39
Mulliodichthys martinicus, 131
Mura tenuispina, 211
Murgantia listrionica, 276
muricata, Pontobdella, 167
Musca domestica, 339–340
Musk ox, 100
Mussel scale, 281
Mussels, 39, 114, 117, 126, 127, 203, 208, 233, 252
Muskrat, 2
Mya, 209
Myiapoda, 215, 241–246
Myrmecocystus hortideorum, 336
Myrmecophana, 263
Mysidacea, 222
Mytilus edulis, 39, 127, 252
Myzostomata, 166

narbonensis, Lycosa, 360
natans, Polynema, 319
Nautilus, 65
Nautilus, 209, 212
navalis, Teredo, 175, 209
Nebalia bipes, 221
Needle-bug, 278
Nemathelminthes, 163, 170–171
Nematodes, 163, 170–171
Nemertinea, 163, 168
Neoceratodus forsteri, 16
Nephrops norvegicus, 39
Nereis, 165
N. caudata, 165
N. dumerilii, 165
N. furcata, 162, 233
Neuroptera, 258, 287
Newts, 9, 148
Noctiluca, 140
N. scintillans, 139
nodosus, Chernes, 361
North American hawk moth, 295
North American slug, 195
norvegicus, Nephrops, 39
Notonecta, 319
N. glauca, 314
Nummulites, 195

Obelia, 151, 152
oblongus, Borus, 201, 216
obtusata, Littorina, 94
obtusata, Sphaerotherium, 246
Octopus, 198, 203, 209–212, 214, 239
Octopus vulgaris, 209
Ocypoda, 228
Ocypus olens, 306
Ocyurus chrysurus, 131
Odonata, 258, 270–272, 312
Odostomia rissoides, 233
Oecophylla smaragdani, 254
Oestridae, 349
Oestrus ovis, 341, 349
officinalis, Sepia, 210
Oil beetles, 308–309, 349
olens, Ocypus, 306
oleracea, Eurydema, 276
Opalina, 142
operculata, Sertularia, 152
Ophiactis savigni, 148
Ophiodaphne materna, 188
Ophionotus hexactis, 187, 188
Ophiopholis aculeata, 148
Ophiothrix fragilis, 187
Ophiura albida, 247
Opiliones, 361
Opisthobranchia, 206–207
Opposum shrimp, 222, 224
Orasema viridis, 318
Orb spiders, 359
Orb-spinning spider, 354
Oriental peach moth, 286
orientalis, Blatta, 259
Ormers, 204
Orthoptera, 258, 259–264
Oryctus boas, 309
oryzae, Calandra, 307
Ostracoda, 218
Ostrea edulis, 39
O. virginicus, 39, 252
Ostrich, 71, 110
Otter, 121
ovis, Oestrus, 341, 349
Owls, 111
Owl butterfly, 298
Oxpecker, 236
Oysters, 39, 203, 208, 209, 252
Oyster-catcher, 4

Pachyrhamna acanthocera, 263
P. fascifer, 263
Paelamnaeus, 351
Pagrus unicolor, 18
pagurus, Cancer, 252
pagurus, Carcinus, 39
Palaeomonetes varians, 39
Palinurus, 226
pallida, Biorhiza, 318
Palola, 166
Paludicella, 190
Pandorina, 46
Pandinus imperator, 238
Panesthia lata, 260
Paper nautilus, 212
Paper-wasps, 324, 326, 333
Papilio clytia var. *dissimilis*, 248
P. clytia var. *panope*, 248
P. machaon, 289
Paractopus apollyon, 214
paradoxus, Metoecus, 349–350

Paragonimus westermanni, 174
Paramecium bursaria, 232
Paramoecium, 22, 140, 141, 142, 252
P. caudatum, 140
Parasitica, 317, 318–320
parasitica, Calliactis, 233
parra, Haemulon, 133
Passenger pigeon, 70–71, 106
Patella vulgata, 203
Pea crab, 228, 247
Pearly nautilus, 209, 212
Pecten, 209
Pelagia noctiluca, 155
Pelagohydra mirabilis, 72
Pelicinus, 317
Peracarida, 222
Perilampus chrysopae, 318
P. hyalinus, 319
Peripatus, 241–244, 255, 290
Periplaneta americana, 259
Periwinkle, 39, 201, 203, 204
Perla, 263
perniciosus, Aspidiotus, 281
persuasoria, Rhyssa, 319
petrolei, Psilopa, 343
Petroleum-fly, 343
Petrel, 66
phalangoides, Folcus, 86
phalangioides, Pholeus, 358
phasma, Protella, 225
Pheidole, 332
Philaeus spumarius, 281
Pholeus phalangioides, 358
Phonoctonus, 277
Phyganea, 315
Physa, 207
Physalia, 153
Physophora, 153
Phytometra brassicae, 350
Phytophaga, 317–318
piceus, Hydrous, 314
Pig, 142
Pigmy beetle, 303
Pila luzonica, 174
pilosa, Membranipora, 191
Pine saw-fly, 52
Pinnotheres pisum, 247
pipiens, Culex, 339
pisum, Pinnotheres, 247
Plagiobrissus grandis, 184, 185
Plankton, 85
Plant-lice, 34, 96, 248–252, 275, 278–281, 286, 322, 348
Platyhelminthes, 147, 163, 168–170
Plecoptera, 258, 264
plexippus, Danaus, 296
Pogonomyrmex, 336
Polynema natans, 319
Polyphaga, 306–311
Pomerine ant, 322
Polar bear, 25
Polydora ciliata, 39
Polyoza, 189–191
polyphemus, Limulus, 64
Polystomella, see *Elphidium*
Polystomum, 169
Pomacanthus aureus, 122
Pond skater, 277, 312
Pond snail, 207
Pontobdella muricata, 167
Popillia japonica, 285
Poplar hawk moth, 257
Porcelain crab, 227
Porcellis scaber, 216
Pork tapeworm, 170, 173
Porkfish, 133
Port Jackson shark, 65
Portuguese man-o'-war, 152
Portunus depurator, 228
Potter-wasp, 324
Pouched shrimp, 222
Powder-post beetle, 308
Praon, 319
Prawns, 121, 128, 218, 220–221, 223, 224–229, 231
Praying mantis, 15, 91, 113, 115, 229, 256, 277, 259–264, 278, 320
princeps, Architeuthis, 210, 214
Processionary moth, 304
Pronuba, 295
P. yuccasella, 295
Protella phasma, 225
proteus, Amoeba, 10, 27, 28–29, 30, 32, 34, 35, 37, 41, 44, 46, 47, 48, 77, 135, 137, 138
Protozoa, 135–143
Protracheata, 215, 241–246
Protura, 258
Psalmopaeus cambridgeii, 356
Pseudorca crassidens, 72
Psilopa petrolei, 343
psiltacus, Xyrichthys, 73
Psithyrus, 329
Psocoptera, 258, 269
Psorophora, 344
Pterodactyl, 60
Ptychomyia remota, 284
Pulmonata, 207
Puma, 40, 75
punctatum, Anobium, 308
punctatum, Sphenodon, 66
purchasi, Icerya, 284
Purse-sponge, 44
Puss moth, 295

quadripustulata, Winthemia, 348
quinquisperforata, Mellita, 185

Rabbits, 282
Raccoon, 77, 78
radiata, Astropyga, 183
Rag-worm, 85, 165, 233

Raia clavata, 167
Rats, 140, 239, 282
Razorbill, 30
Razorfish, 73
Red grouper, 132
Red parrot fish, 133
Red robber ant, 322
Red spider, 362
Red underwing moth, 302
Red-tailed tachina fly, 348
Reduvoidea, 277
Reindeer, 49
remota, *Ptychomiya*, 284
Rhabdopleura, 193
Rhinoceros, 236
Rhinoceros beetle, 309
Rhizopoda, 137
Rhombus, 39
Rhynchites betulae, 310
Rhyssa persuasoria, 319
Rhytina, 69
Ribbon worms, 163, 168
Rice bug, 276
Rice weevil, 310
Riela manticida, 319–320
Ringed worms, 163, 164–166
rissoides, *Odostomia*, 233
Robber crab, 227
Robber-fly, 255, 342, 343, 344, 345
Rock barnacles, 218
Rock lobster, 103, 226
roscoffensis, *Convoluta*, 168, 232
Rotifera, 163, 166–168
Roundworms, 163, 170–171, 172
rubens, *Asterias*, 39, 176, 252
ruber, *Caranx*, 133
rugipes, *Tropicores*, 275
Runner, 133

Sabella, 164
Sabre-toothed tiger, 62
saccharina, *Lepisma*, 14
Sacculina, 221, 222
Sacred beetle of Egypt, 309
Sailor's choice, 133
Salamander, 9
San José scale, 281
Sand crab, 227
Sand dollar, 185
Sand-hopper, 121, 220–221, 222, 223
Sand-urchins, 185
Sand-wasp, 323, 326
sanguinea, *Formica*, 336
sanguinolenta, *Henricia*, 39, 187
sapiens, *Homo*, 18
Sarcophagidae, 348–349
sarsi, *Luidia*, 187
Saturnid butterfly, 296
savigni, *Ophiactis*, 148
Saw-fly, 34, 258, 317
saxatilis, *Littorina*, 94
scaber, *Porcellis*, 216
Scalariform snail, 175
Scale-insects, 275, 278–281
Scallops, 208, 209
Scaphopoda, 198, 208
Scarab beetle, 309
scenicus, *Galticus*, 360
Schistocera, 348–349
Schnapper, 18
Schoolmasters, 131
scintillans, *Noctiluca*, 139
sciurus, *Haemulon*, 131, 133
Scolopendra gigas, 245
Scorpionidae, 351–352
Scorpions, 238, 351–352, 360–361
Scorpion-flies, 258
Screech owl, 111
Scyphozoa, 152, 153–155
Scyphistoma, 154
Sea-anemone, 33, 38, 150, 152, 155–158, 161, 233, 234–235, 239
Sea butterflies, 206
Sea-cows, 69
Sea crawfish, 226
Sea-cucumbers, 135, 147, 148, 175, 181–182, 184, 187
Sea-fans, 152, 155–158
Sea-firs, 150, 152, 153
Sea gooseberries, 158
Sea-hares, 206
Sea-leech, 167
Sea-lily, 72, 147, 175, 182, 185, 187, 189
Sea-mosses, 51, 150, 166
Sea mussel, 233
Sea-orange, 147
Sea-pens, 152, 155–158
Sea skater, 277
Sea slug, 206
Sea-star, 148, 186
Sea-urchin, 46, 126, 133, 134, 175, 180–181, 183–185, 186–188
Sea-wolf, 132
Seals, 123, 124
Secretary bird, 110
Sepia officinalis, 210
septemdecim, *Tibicina*, 280
septempunctata, *Coccinella*, 307
Sertularia, 151, 152, 154
S. operculata, 152
setosus, *Centrechinus*, 180
Seven-spotted ladybird, 307
Seventeen-year locust, 280
Sexton beetle, 306
Sharks, 132
Sheep, 43, 106, 236
Sheep bot-fly, 341
Sheep house-fly, 341
Sheep tick, 341
Sheep-nostril fly, 349

Shield bugs, 275–276
Shipworms, 175, 176, 209
Shore bugs, 277
Shore-crab, 222
Short-horned grasshopper, 262, 263
Shot-hole borer, 310
Shrimps, 39, 121, 218, 220–221, 222, 223, 224–229
Sialis, 315
Silpha sinuosa, 309
Silver-fish, 14, 18
sinuosa, *Silpha*, 309
Siphonaptera, 258, 346–347
Sirex gigas, 319
Skipjacks, 308
Skunk, 81
Slater, 216
Slave-maker, 336
Slipper animalcule, 140, 141, 142
Slipper limpet, 205
Slugs, 195, 197, 198, 199–208, 213, 247
smaragdani, *Oecophylla*, 254
Snails, 33, 168, 171, 175, 197, 199–208, 213, 216
Snake millipede, 245
Snow-flies, 281
Social-wasps, 323, 324, 332
Solifugae, 360
Solitary ants, 322
Sole, 39
Solea, 39
solium, *Taenia*, 170, 173
South African pill, 246
Sow-bugs, 222–223
Sparisoma abildgaardi, 133
Sparrowhawks, 118
Specoid wasps, 322
Sphaerosyllis tetralix, 39
Sphaerotherium obtusum, 246
Sphaerozoum, 46
Sphenodon punctatum, 66
Sphyraena barracuda, 132
Spiders, 85, 86, 88, 89, 116, 118
Spider crabs, 227, 239, 240, 299
Spider-hunters, 323
Spiny lobsters, 225, 226
spiralis, *Venetus*, 211
Spirorbis, 165
Spittle insect, 281
Sponges, 33, 36, 37–38, 44, 47, 48, 58, 120, 121, 131, 135–148, 143–147, 148, 178
Spoonbills, 102
Spotted salamander, 9
Spring tail, 118
Spring-tail, 258, 312
spumarius, *Philaeus*, 281
squamata, *Amphipolis*, 188
squamata, *Clava*, 150
Squash bug, 276
Squat lobster, 227, 228
Squid, 132, 198, 203, 209–212, 214
squinado, *Maia*, 239
Squirrel fish, 130
Stable-flies, 340
Stag beetle, 309
stagnalis, *Limnaea*, 207
Stalked barnacle, 219
Starfishes, 39, 125, 148, 175–180, 181, 184, 202, 203, 231, 252
Starling, 191, 236
Statoblasts, 194
Stegosaurus, 61
stellaris, *Betaurus*, 82
stelleri, *Cryptochiton*, 198
Stem saw-fly, 318
Stenoglossa, 205–206
Stenobothrus bicolor, 262
Stentor, 141, 142
Stick insects, 34, 259–264, 277, 311
Stink bugs, 276
Stoicactis, 161
Stomatopoda, 228–229
Stone crabs, 227
Stone-flies, 258, 264
Striped yellow grunt, 133
Strongylocentrus francisarus, 183
Sturnus vulgaris, 191
Stylifer, 202, 203
Sucker-mouthed worms, 166
Sucking lice, 269, 347
Sundew, 36
Swallowtail butterfly, 289
Swan mussel, 203
Sweat-fly, 338
sycophanta, *Calosoma*, 282
Synapta maculata, 181
Synura, 139

Tadpole snail, 207
Taenia solium, 170, 173
Tanaidacea, 222
Tanusia brullei, 263
Tapeworm, 162, 169, 170, 172, 173, 174
Tarantula spider, 324, 354–355
tasmaniae, *Anaspides*, 221
Tasmanian wolf, 5
Tealia felina, 33
Technitella thomsoni, 135
Telescope-eyed goldfish, 248
Tellina tenuis, 105
Tendipedidae, 315–316
tenuis, *Tellina*, 105
tenuispina, *Murex*, 211
Teredo, 211
T. navalis, 175, 209
Termites, 140, 258, 264–272, 330
terrestris, *Julus*, 245, 246
tessellata, *Melia*, 228
tesselletum, *Xestobium*, 308
Testacella, 207
Tethya aurantium, 147
tetralix, *Sphaerosyllis*, 39

Tetralobus flabellicornis, 308
Tetramorium caespitum, 336
Thalessa, 319
Thamnotrizon cinerius, 263
Thermosbaenacea, 222
thomsoni, *Technitella*, 135
thoracia, *Gerris*, 312
Thornback skate, 167
Thorny-headed worms, 163, 172
Thrips, 258, 275
Thylacine, 69
Thylacine wolf, 5
Thylacinus cynocephalus, 5
Thysanoptera, 258, 275
Thysanura, 258
Tibicina septemdecim, 280
Ticks, 236, 362–363
Tiger beetle, 303–306
Tipula gigantea, 337
Tjalfiella, 158
Toe-biter, 278
Tolypeutes tricinctus, 246
Tomato sphinx caterpillar, 346
Tooth-shells, 205
Top shells, 204
Tortoise, 42
Trapdoor spider, 357
Tree-locust, 263
Tree-wasp, 325
Trematoda, 169–170
Triceratops, 62
Trichogramma, 286
Trichoptera, 258, 288
tricinctus, *Tolypeutes*, 246
Tricondyla aptera, 304
Tridacna, 180, 208, 233
Trilobite, 65
tristis, *Anasa*, 276
Trochelminthes, 163, 166–168
Troctes divinatorius, 269
Trombicula autumnalis, 362
Tropicoris rugipes, 275
True bugs, 275-278
True crabs, 227
True limpets, 204
True wasps, 322
Trumpet animalcule, 141, 142
truncatellus, *Litomastix*, 350
tryoni, *Dacus*, 339
Trypanosoma lewisi, 140
Tsetse-fly, 140, 338, 340
Tuatara, 66
tuberculata, *Haliotis*, 204
tuberculosa, *Argonauta*, 212
tuberosa, *Ebalia*, 240
Tumble beetles, 309
Turbellaria, 168–169
Turbot, 39
Turret-shell snail, 213
Tusk-shells, 208
Two-spotted ladybird, 251, 307
typicus, *Archaster*, 188

Uintatherium, 63
unicolor, *Pagrus*, 18
unilifera, *Luidia*, 148
Ursus arctos, 2
urticae, *Vanessa*, 290

vallentini, *Euphausia*, 128, 129
Vanessa urticae, 290
varia, *Misumeria*, 355
varians, *Palaemonetes*, 39
varians, *Hippolyte*, 225
variopedatus, *Chaetopterus*, 39
Vedalia cardinalis, 284, 307
Velvet-wasps, 322
Venus' flower basket, 144
Venetus spiralus, 211
Vermes, 163–174
Vespa crabs, 332
Vespoid wasp, 322
Vespula, 332, 334, 336
V. vulgaris, 350
Vinegar eels, 170
violaceus, *Carabus*, 304
virginica, *Ostrea*, 252
virginicus, *Anisotremus*, 133
virginicus, *Ostrea*, 39
viridis, *Hydra*, 232
viridis, *Orasema*, 318
Volvox, 46, 139, 194
Vorticella, 142
vulgare, *Armadillium*, 246
vulgaris, *Crangon*, 225
vulgaris, *Homarus*, 39, 226
vulgaris, *Lutra*, 121
vulgaris, *Melolontha*, 310
vulgaris, *Octopus*, 209
vulgaris, *Sturnus*, 191
vulgaris, *Vespula*, 350
vulgata, *Ephemera*, 270
vulgata, *Patella*, 203

Warble-flies, 338, 341, 349
Wasps, 115, 258, 283, 300, 312, 317, 320–336, 348, 349, 350
Water-beetles, 303–306, 308, 314
Water-boatman, 272, 278, 319
Water-bugs, 275, 277–278, 316
Water-crickets, 278
Water-fleas, 217, 218
Water-mites, 362
Water-scorpion, 278
Water-snail, 169
Watering-pot shells, 211
Weevils, 303, 307, 310
westermanni, *Paragonimus*, 174
Whale lice, 223
Whales, 122–123, 218, 252

Wheel animalcules, 163, 166–168
Whelk, 121, 197, 199–208, 218
Whirligig-beetles, 305-306, 312, 315
White ants, 140, 258, 329–330
White grubs, 310
Whitetailed goldfish, 248
Winkles, 252
Wildebeest, 8, 100
Winthemia quadripustulata, 348
Wire-worms, 245, 246
Wolf-spider, 84, 88, 354, 355, 359
Woodchuck, 90
Woodlice, 121, 199, 216, 218, 220–221, 222–223, 246
Woodpeckers, 118
Woodworms, 308
Woolly aphis, 250
Worms, 33, 39, 121, 126, 163–174, 192, 218, 231, 254
Worm-shells, 205, 211
Wrasse, 239
Wuchereria bancrofti, 344

Xenia, 160
Xestobium tesselletum, 308
Xiphosura, 351
Xyrichthys psiltacus, 73

Yellow ant, 306
Yellow goatfish, 131
Yellow grunt, 131
Yellow jacket wasp, 323
Yellowtail fish, 131
Yucca moth, 295
yuccasella, Pronuba, 295

Zalophus californianus, 16
Zebra, 8, 100
Zebra spider, 363–364
zibethicus, Fiber, 2
Zoraptera, 258, 269

SUBJECT INDEX

Aberrant animals, 175–188
African front, 107–116
Alder-flies, 287
Anemotropism, 86, 89
Animal, definition of, 37–38
Animal kingdom, classification of, 20
Animal life, succession of, 58
Animal, the simplest, 28–29
Animals, form in, 236–238
Animals known from single specimens, 116
Animals of uncertain origin, 189–194
Animals recently become extinct, 67–69
Ant-lions, 287
Ants, 317, 320–322, 329–336
Aphides, 248–252; enemies of, 248–252
Arrow-worms, 172
Atavism, 17–18
Antarctic Convergence, 128

Barnacles, 218–219
Beauty in repetition, 183–185
Bees, 317, 328–336, 320, 321
Beetles, 303–311
Behaviour, analysis of, 81–84; animal, 32–34; meaning of, 73–74; similarity of, 74–81
Bivalves, 198, 208–209
Book-lice, 269
Bridge worms, 163, 166
Bristle-jaws, 172, 258
Bristle-worms, 163, 164–166
Bugs, 275–281
Butterflies, 288–298

Caddis-flies, 288
Caterpillars, 288–298
Cell, the living, 30–31
Cells, multiplication of, 46–47
Centipedes, 244–246
Chemotropism, 86
Chitons, 197, 198–199
Cicadas, 278–281
Coat-of-mail shells, 197, 198–199
Cockroaches, 259–264
Colorado beetle, 310
Comb-bearers, 152, 158
Communities, analysis of animal, 97
Coral reefs, formation of, 158–162
Corals, 155–162
Crabs, 224–249, 238–239, 351
Crayfishes, 224–229
Crustaceans, 215–229

Darwinism, 53–54
Degeneration, 193–194
Diatom ooze, 124
Diploblastic animals, 149
Dragon-flies, 270–272

Earthworms, 163, 164–166
Earwigs, 259–264
Echinoderms, propagation of, 186–188
Egg populations, 39, 79
Embryo, 253
Environment and habitat, 107
Evolution, 52–54, 193–194; primary mechanism of organic, 34–37

Feather-stars, 175–182
Fecundity, 252–253
First animals, the, 135–148
Flagellates, 138
Flatworms, 163, 168–170; and human welfare, 172–174
Fleas, 346–347
Flies, two-winged, 337–347
Flukes, 169–170
Food chains, 118
Form, variation in, 247–248
Fossils, 8, 55; living, 64–67

Gall-flies, 318–320
Galvanotropism, 86, 89
Gemmules, 194
Generations, alternation of, 51, 150–158
Geographical distribution, 126–128
Geological record, 55–71
Geotaxis, 86
Geotropism, 86
Globigerina ooze, 124
Grasshoppers, 259–264
Growing, 41–43

Habit, similarity of, 246
Habitat and environment, 107
Habitats, structure, 97–102
Heliotaxis, 86
Heliotropism, 86
Helminths and human welfare, 172–174
House-fly, 339–340
Human welfare, 172–174
Hydrotropism, 86
Hygrotropism, 86, 88

Ichneunon-flies, 318–320
Insects, 247–350; biological control of, 282–286; parasitism in, 347; respiration in, 312–316; social habits of, 329–336
Invertebrates, marine, 39

Jumping spider, 363–364

King crabs, 351

Lace corals, 189–191
Lace-wings, 287
Lamarkism, 53–54
Lamp shells, 191–194
Larva, 253
Leaf-hoppers, 278–281
Lice, 269
Life, background, 95–118; cradle of, 119–134; expression of, 73–94; history of, 55–72; mechanics of, 41–54; origin of, 21–24
Living, 41–43
Living matter, fundamental needs of, 28
Living together, different ways of, 231–236
Lobsters, 224–229
Locusts, 259–264

May-flies, 269–270
Millipedes, 244–246
Mimicry, 301–302
Mites, 362–363
Molluscs, 197–214
Morphology, meaning of, 5
Mosquitoes, 338–339
Moss animals, 189–191
Moths, 288–298
Multicellular animals, 44–46

Natural balance, delicacy and stability of, 102–104
Nematocysts, 149–150
Neo-Darwinism, 53–54
Nettle-cells, 149–150
Nymph, 253

Octopus, 198, 209–212; giant, 214
Offspring unlike parents, 51–52
Overcrowding, 231
Ovipary, 216

Parasitism, 347
Parental care, 72
Parthenogenesis, 50–51
Passenger pigeon, extermination of,70–71
Peripatus, 241–244
Physiology, meaning of, 5
Phototaxis, 86
Phototropism, 86
Plankton, 125
Plant-lice, 278–281
Populations, study of animal, 104–105
Prawns, 224–229
Praying mantis, 259–264
Protective coloration in insects, 298–301

Rare animals, 72
Regeneration, 147–148
Relics of bygone days, 191–194
Reproduction, 30, 33, 43–44; without sex, 50–51
Respiration in aquatic insects, 312–316
Reversion, 17–18
Rheotropism, 86, 88
Ribbon worms, 163, 168
Roundworms, 163, 170–171; and human welfare, 172–174
Rudimentary, meaning of, 16–17

Sacred flame, the, 91–93
Scale insects, 278–281
Scorpions, 351–352
Sea-anemones, 155–158
Sea-cucumbers, 175, 181–182
Sea-fans, 155–158
Sea, life in the, 119–128; life under the, 129–134
Sea-lilies, 175, 182
Sea-pens, 155–158
Sea-urchins, 175, 180–181
Senses of insects, 301–302
Sex, evolution of, 47–49; origin of, 47–49
Sexual characters, secondary, 49–50
Shellfish, soft-bodied, 197–214
Slugs, 197, 199–208
Snails, 197, 199–208
Speed in insects, 272–274
Spiders, 352–360, 363–364
Sponges, 135–148
Squids, 198, 209–212; giant, 214
Starfish, 175–180
Statoblasts, 194
Stereotropism, 86, 88
Stick insects, 259–264
Stinging-cells, 149–150
Surroundings of animals, 95, 194
Symbiosis, 232–233
Systematics, study of, 13–19

Tape-worms, 170
Taxonomy, 13–19
Termites, 264–272
Thermotropism, 86
Thigmotropism, 86

Thorny-headed worms, 163, 172
Thrips, 275
Ticks, 362–363
Tiger beetles, 303–306
Trace elements, effects of, 105–107
Triploblastic animals, 149, 196
Tropism, 85–93

Unicellular animals, 44–46, 135–143

Vermes, 163–174
Vestigial, meaning of, 16–17
Vibrotropism, 86, 88
Viruses, 24–37
Vivipary, 216

Wasps, 317, 322–336
Weevils, 310
Wheel animalcules, 163, 166–168
Whelks, 197, 199–208
Worms, 163–174

Zebra spider, 363–364
Zoology, meaning of, 3–12